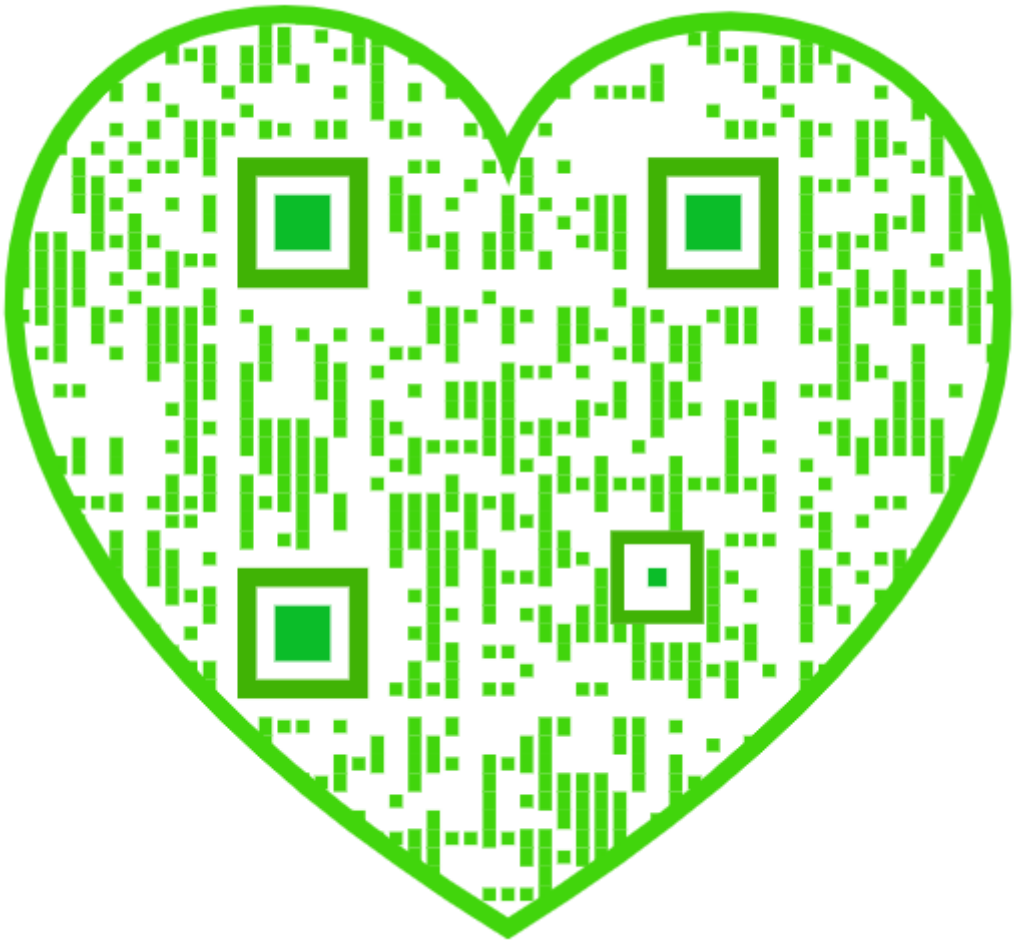
3 1761 04383 1619

entury's
rogress
Astronomy

Handle with
EXTREME CARE
This volume is damaged or brittle
and CANNOT be repaired!
• photocopy only if necessary
• return to staff
• do not put in bookdrop
Gerstein Science Information Centre

HECTOR MACPHERSON, Jun.



A Century's Progress in Astronomy

Astron

A Century's Progress

IN

Astronomy

86421
Y 1/4/08

BY

HECTOR MACPHERSON, JUN.

MEMBER OF THE SOCIÉTÉ ASTRONOMIQUE DE FRANCE;
MEMBER OF THE SOCIÉTÉ BELGE D'ASTRONOMIE;
AUTHOR OF 'ASTRONOMERS OF TO-DAY'

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MCMVI

All Rights reserved

PREFACE.

THE present volume originated in a desire to present, in small compass, a record of the marvellous progress in astronomy during the past hundred years. Indebtedness should be acknowledged to the valuable works of Professor Newcomb, Professor Schiaparelli, Professor Lowell, Professor Young, Sir Robert Ball, Mr Gore, M. Flammarion, and Miss Clerke, who, as the historian of modern astronomy, occupies a place at once authoritative and unique.

Portions of Chapters II. and XII. have already appeared in the form of an article on the Construction of the Heavens, contributed by the writer to the American periodical, 'Popular Astronomy.'

BALERNO, MID-LOTHIAN,
October 1906.

CONTENTS.

CHAPTER I.

HERSCHEL THE PIONEER.

PAGE

Influence of Herschel's work—His characteristics—Birth and early years—Emigration to England—Caroline Herschel—Discovery of Uranus—King's Astronomer—Latter years and death—Death of Caroline Herschel 1

CHAPTER II.

HERSCHEL THE DISCOVERER.

Solar researches—Study of Venus—Of Mars—The Asteroids—Jupiter—Saturn—Discovery of satellites—Uranian satellites—Cometary researches—Motion of the Solar System—Discovery of binary stars—Clusters and nebulæ—Nebulous stars—The Nebular Hypothesis—Star-gauging—The disc-theory—Subordinate clusters—Abandonment of the disc-theory—Second method of star-gauging—Estimate of Herschel's work 15

CHAPTER III.

THE SUN.

Schwabe and the sun-spot period—Researches of Wolf, Lamont, Sabine, Gautier—Observations of Carrington

and Spörer—Career and work of Fraunhofer—Spectrum analysis—Work of Kirchhoff—Solar eclipse work—The Solar prominences—Janssen and Lockyer—Huggins and Zöllner—Work of Young—The Italian spectroscopists, Secchi, Respighi, Tacchini—Career of Tacchini—The reversing layer—The Corona—Doppler's principle—Rotation of the Sun—Work of Dunér—Janssen's solar atlas—Maunder and magnetism—Solar theories—Distance of the Sun—Summary 43

CHAPTER IV.

THE MOON.

Life and work of Schröter—Of Mädler—Of Schmidt—Changes on the Moon—Selenography in England—Lunar atmosphere—Lunar photography—Work of W. H. Pickering—The new Selenography—The Moon's heat—Motion of the Moon—Acceleration of the Moon's mean motion—Work of Laplace, Adams, Delaunay . . 65

CHAPTER V.

THE INNER PLANETS.

The problem of Vulcan—Mercury—Work of Schröter—Schiaparelli, his life and work—Work of Lowell—Spectrum of Mercury—Venus—Rotation period: work of Schröter, Di Vico, Schiaparelli, Tacchini, Lowell—Atmosphere and surface of Venus—The Earth: variation of latitude—Mars—Rotation of Mars—Surface—Discovery of canals—Work of Schiaparelli and Lowell—Interpretation of the canals—The theory of intelligent life—Spectrum of Mars—Satellites—The Asteroids—Bode's law—Work of Piazzi and Olbers—Application of photography by Wolf—Discovery of Eros 80

CHAPTER VI.

THE OUTER PLANETS.

Physical condition of Jupiter—Work of Zöllner and Proctor —The red spot—Satellites—Discovery of fifth satellite— Sixth and seventh satellites—Rings of Saturn: Bond, Maxwell, Keeler—Struve's theory—Globe of Saturn— New satellites—Uranus and its satellites—Discovery of Neptune—Adams and Le Verrier—Satellite—Trans-Neptunian planets 103

CHAPTER VII.

COMETS.

Life and work of Olbers—His repulsion theory—Life and work of Encke—His comet—Biela's comet—Faye's comet —Return of Halley's comet—Donati's comet—Comet of 1861—Spectroscopic study of comets—Theory of Brédikhine—Spectra of comets—Comets of 1880 and 1882—The capture theory—Cometary photography . . . 123

CHAPTER VIII.

METEORS.

Meteoric shower of 1833—Work of Olmsted—Work of Erman and Kirkwood—Of H. A. Newton—Adams and the meteoric orbit—Shower of 1866—Connection of comets and meteors—Work of Schiaparelli—Shower of meteors in 1872—'Le Stelle Cadenti'—Meteoric observation—A. S. Herschel—Work of Denning—Stationary radiants—Bolides and aerolites—Origin of aerolites . . . 138

CHAPTER IX.

THE STARS.

Distance of the stars—Life and work of Bessel—Studies of Struve—Life and work of Henderson—Work of Peters, Otto Struve, Brünnow, and Ball—Measures of Gill—Parallax of first-magnitude stars—Relative and absolute parallax—Work of Kapteyn—Application of photography—Star-catalogues—Argelander's 'Durchmusterung'—Work of Schönfeld—Work of Gould—The 'Cape Photographic Durchmusterung'—Work of Gill and Kapteyn—International chart of the heavens—Work of Peck—Proper motions of the stars—Star-drift—Discoveries of Proctor and Flammarion—Radial motion—Work of Huggins, Vogel, and Campbell—Solar motion . . . 150

CHAPTER X.

THE LIGHT OF THE STARS.

Work of Fraunhofer and Donati—Life and work of Secchi—His types of spectra—Life and work of Huggins—Photography of spectra—Life and work of Vogel—His classification of spectra—Work of Dunér—Of Pickering—Spectroscopic catalogues—Analysis of spectra—Stellar photometry—Life and work of E. C. Pickering—Variable stars—Work of Goodricke—Of Argelander, Schmidt, Heis, Schönfeld—Studies of Dunér—Of Gore—Photographic discoveries—Classification—Algol variables: their explanation—Explanation of other variables—η Argus—Temporary stars—Of 1848—Of 1866—Of 1876—Of 1885—Of 1892—Photographic discoveries—Nova Persei, 1901—New star of 1903—Theories of temporary stars . . 169

CHAPTER XI.

STELLAR SYSTEMS AND NEBULÆ.

Life and work of John Herschel—Binary stars—Computation of orbits—Work of Wilhelm Struve—Of Otto Struve—Of Burnham—Satellites of Sirius and Procyon—Astronomy of the invisible—Work of Pickering and Vogel—Spectroscopic binaries—Work of Bélopolsky and Campbell—Star-clusters—Nature of nebulæ—Spectroscopic work of Huggins—Of Copeland—Nebular photography—Work of Roberts, Barnard, Wolf—Of Keeler . . . 197

CHAPTER XII.

STELLAR DISTRIBUTION AND THE STRUCTURE OF THE UNIVERSE.

Work of John Herschel—Researches of Wilhelm Struve—Extinction of light—Mädler's "central sun"—Distribution of nebulæ—Work of Proctor—Aggregation of stars on the Galaxy—Work of Gore and Schiaparelli—Studies of Gould—Researches of Kapteyn—Of Newcomb—Is the Universe limited? Newcomb's argument—Observations of Celoria—Researches of Seeliger—External Universes—Gore's speculations 214

CHAPTER XIII.

CELESTIAL EVOLUTION.

Laplace's nebular hypothesis—Helmholtz and solar contraction—Theories of solar heat—Objections to Laplace's theory—Faye's hypothesis—Ball's exposition—The meteoritic theory of Proctor—Its extension by Lockyer—Evolution of the stars—Vogel's order of evolution—Tidal friction: work of Darwin—See's explanation of double stars—Future of the Universe 227

A CENTURY'S PROGRESS IN ASTRONOMY.

CHAPTER I.

HERSCHEL THE PIONEER.

In astronomy, as in other sciences, the past hundred years has been a period of unparalleled progress. New methods have been devised, fresh discoveries have been made, new theories have been propounded; the field of work has widened enormously. In fact, the science of the heavens has become not only boundless in its possibilities, but more awe-inspiring and marvellous.

To whom in the main is this great advance due? To the great pioneer of what may be called modern astronomy — William Herschel. Not only did Herschel reconstruct the science and widen its bounds, but his powerful genius

directed the course of nineteenth century research. As an astronomical observer he has never been surpassed. In the breadth of his views he was equalled only by Newton; and indeed he excelled Newton in his unwearied observations and his sweeping conceptions of the Universe. To quote his own remark to the poet Campbell, he "looked farther into space than ever human being did before him."

Herschel studied astronomy in all its aspects. In all the branches of modern astronomy he was a pioneer. He observed the Sun, Moon, and planets, devoting special attention to Mars and Saturn. He doubled the diameter of the Solar System by the discovery of Uranus. He discovered several satellites and studied comets. He was pre-eminently the founder of sidereal astronomy. He discovered binary stars, thus tracing the law of gravitation in the distant star-depths; while to him is due the credit of the discovery of the motion of the Solar System. He founded the study of star-clusters and nebulæ, propounded the nebular hypothesis, and devised two methods of star-gauging. Above all, he was the first to attempt the solution of one of the noblest problems ever attacked by man—the structure of the Universe. In fact, the latter problem was the end and aim of his observations. As

Miss Clerke remarks, "The magnificence of the idea, which was rooted in his mind from the start, places him apart from and above all preceding observers." Most of the departments of modern astronomy find a meeting-place in Herschel, as the branches run to the root of the tree. He discussed astronomy from every point of view. Before, however, proceeding to examine the work of this great man, it is well to note a few of his characteristics. These characteristics, once understood, give us the key to his researches. Before we can master Herschel the astronomer we must understand Herschel the man.

Notwithstanding the fact that Herschel spent most of his life in England, and that he is included in the 'Dictionary of National Biography,' he was pre-eminently a German. Like most Germans his style of writing was somewhat obscure, and this was emphasised when he wrote in English, owing to his imperfect command of the language. Had he written in German as well as in English, he would probably have been better understood in his native country, where erroneous views of his theories were long entertained. Even so distinguished an astronomer as Wilhelm Struve, when translating Herschel's papers into German, made a mistake when

translating a certain passage, which leaves the erroneous impression that Herschel believed the Universe to be infinite—a mistake which would not have arisen had he written in German.

The student of Herschel should also be careful in quoting the views of the great astronomer. Had Herschel at the close of his life written a volume containing his final views on the construction of the heavens, this would not have been necessary; but Herschel did not write such a volume. His researches were embodied in a series of papers communicated to the Royal Society from 1780 to 1818. As he observed the heavens his opinions progressed, so that a statement of his views at any given time was by no means a statement of his final opinions. The late R. A. Proctor, who was the first great exponent of Herschel in England, has well said: "It seems to have been supposed that his papers could be treated as we might treat such a work as Sir J. Herschel's 'Outlines of Astronomy'; that extracts might be made from any part of any paper without reference to the position which the paper chanced to occupy in the entire series."

Herschel, like the true student of nature, held theories very lightly. They were to him but roads to the truth. Unlike many scientists,

he did not interpret observations by hypothesis: he framed his theories to fit his observations. If he found that a certain theory did not agree with what he actually saw in the heavens, he abandoned it: he did not hesitate to change his views as his investigations proceeded. "No fear of 'committing himself,'" says Miss Clerke in her admirable work on 'The Herschels,' "deterred him from imparting the thoughts that accompanied his multitudinous observations. He felt committed to nothing but truth."

In the mind of Herschel imagination and observation were marvellously blended. He was a philosophical astronomer. Although his imagination was a very vivid one he did not allow his fancies to run away with him, as Kepler sometimes did: on the other hand, he did not, like Flamsteed, refrain from speculating altogether. "We ought," he wrote in 1785, "to avoid two opposite extremes. If we indulge a fanciful imagination, and build worlds of our own, we must not wonder at our going wide from the path of truth and nature. On the other hand, if we add observation to observation, without attempting to draw not only certain conclusions but also conjectural views from them, we offend against the very end for which only observations ought to be made."

These characteristics—the lightness with which he held his theories, his vivid imagination, and his philosophical reasoning—are the secrets of Herschel's success as an astronomer. Nearly all his ideas and speculations have been confirmed. As Arago has said, "We cannot but feel a deep reverence for that powerful genius that has scarcely ever erred." Herschel, like all other great students of Nature, was deeply religious. He could not observe the heavens without feeling awed at the marvels which his telescopes revealed. In his own words, "It is surely a very laudable thing to receive instruction from the Great Workmaster of Nature."

Friedrich Wilhelm Herschel, born in Hanover on November 15, 1738, was the fourth child of Isaac Herschel, an oboist in the band of the Hanoverian Guard. Isaac Herschel, a native of Dresden, was an accomplished musician, and all his children, ten in number, inherited his talent. Of these ten, six survived, and only two became famous. These were William, the great astronomer, and his sister Caroline (born on March 16, 1750), who became a student of the heavens only second to her brother.

At the garrison school in Hanover, where the Herschels were educated, William Herschel showed intense love and aptitude for learning,

and was more diligent and persevering than his brother Jacob, his senior by four years. In 1753 he became oboist in the band of the Hanoverian Guard in which his father was now bandmaster. In her valuable memoirs, his sister relates that her father was very interested in astronomy, and that he taught his children the names of the constellations. William became devoted to the science, and constructed a small celestial globe on which equator and ecliptic were engraved. But his studies were much hampered. His mother had a great dislike to learning: she had no sympathy with aspirations, and tried to prevent her children becoming well educated. Above all, the Hanoverian Guard was ordered to England in 1755, when a French invasion was feared, and to that country Herschel proceeded, along with his father and brother.

Returning to Germany in 1756, the Hanoverian Guard was employed the following year in the Seven Years' War. Hanover was invaded by the French, and, conscription being the rule, the musicians were not exempted from service. Under the command of the Duke of Cumberland the Guard suffered a terrible defeat at Hastenbeck. William Herschel spent the night after the battle in a ditch, and decided that

soldiering would not be his profession. He deserted, and, with the consent of his parents, he sailed for England. After his arrival at Dover, he wandered through the country in search of musical employment. At length, in 1760, he was appointed to train the band of the Durham Militia, and four years later paid a secret visit to Hanover, where he was welcomed by his father, whose health was now failing, and by his sister Caroline. In the following year he was promoted to the post of organist at Halifax, and in 1766 he removed to Bath as oboist in Linley's Orchestra. Finally, in 1767, he became organist in the new Octagon Chapel at Bath. Herschel was now twenty-nine years old, and known as a famous musician. As Miss Clerke remarks: "The Octagon Chapel soon became a centre of fashionable attraction, and he soon found himself lifted on the wave of public favour. Pupils of high rank thronged to him, and his lessons often mounted to thirty-five a-week."

In the year of his appointment his father died, aged sixty, after a life of trouble and hardship. His death was a great blow to his daughter Caroline, whom he had educated when her mother was from home. Caroline Herschel was naturally possessed of musical ability, but her

mother and elder brother had determined that she should be a housemaid,—a determination which William, who was devotedly attached to his sister, opposed. Finally, in 1772, he visited Hanover, and took his sister to England with him to act as his housekeeper. But for her unwearied devotion it is doubtful whether William Herschel would have become the great astronomer.

About the time of his appointment in Bath Herschel commenced the study of languages and mathematics, reading Maclaurin's 'Fluxions' and Ferguson's 'Astronomy.' The perusal of the latter volume revived his love for astronomy. After fourteen or sixteen hours' teaching he would retire to his bedroom and read of the wonders of the heavens. His interest increased as he proceeded, until, in his own words, "I resolved to take nothing upon trust, but to see with my own eyes all that other men had seen before me." Accordingly he hired a small reflector. Inquiring the price of a larger instrument, he found it to be quite beyond his means. Then in 1772, when his sister came to keep his house for him, he resolved to make his own telescope. First he tried the fitting of lenses into pasteboard tubes, but this being a total failure, he bought the apparatus of a Quaker

optician who had constructed, or attempted to construct, reflecting telescopes. In June 1773, assisted by his sister and by his brother Alexander, then in Bath, he commenced work. His first speculum mirror was five inches in diameter; and, while it was in process of construction, he was obliged to hold his hands on it for sixteen hours at a stretch, while his sister supplied his food and read 'The Arabian Nights,' 'Don Quixote,' and other tales aloud to him to pass the time. At last, after two hundred failures, he finished a 5-inch reflector, and on March 4, 1774, he observed the Orion nebula. No sooner had Herschel commenced his celestial explorations than he resolved to survey the entire heavens, leaving no spot unvisited.

In 1775 he commenced his review of the heavens, but finding his telescope inadequate he began the work of telescope-making afresh. Meanwhile he had much to distract him from astronomy. In 1776 he became director of the Public Concerts at Bath. Yet his enthusiasm was unbounded: he would run to his house between the acts at the theatre to observe the heavens. In 1779, when observing the Moon from the street in front of his house, a gentleman asked permission to see the celestial wonders, a request which Herschel granted.

The gentleman, Dr Watson of Bath, introduced Herschel to the Literary Society, and we find him in 1780 contributing two papers to the Royal Society on Mira Ceti and the Moon. In the same year he commenced his second review of the heavens, and during its progress he made his first great discovery. On March 13, 1781, while surveying the constellation Gemini, he discovered a faint object distinguished by a disc, which he concluded to be a tailless comet, but which was soon shown to be a new planet beyond the orbit of Saturn. This was the first planetary discovery made within the memory of man. King George III. summoned Herschel to London, and gave him a pension of £200 a-year, with the title of King's Astronomer, pardoning him also for his desertion from the army more than twenty years previously. Herschel then named the new planet the "Georgium Sidus," a title now abandoned and replaced by Uranus.

William and Caroline Herschel now moved to Datchet, near Windsor, in 1785 to Clay Hall, and finally, in 1786, to Slough,—"the spot of all the world," said Arago, "where the greatest number of discoveries have been made." Here Herschel and his sister worked for nearly forty years. He communicated to the Royal Society paper after paper on astronomy in all its aspects.

He also continued the work of telescope-making, and constructed, in 1789, his 40-foot reflector, the wonder of the age. In 1787 his sister was appointed his assistant, and together the Herschels worked from dusk to dawn. Caroline Herschel herself detected eight comets and numerous nebulæ. She relates in her memoirs that on one occasion, while she was acting as assistant, the ink froze in her pen. But such inconveniences mattered not to the Herschels. As Miss Clerke has well remarked, "Every serene dark night was to him a precious opportunity, availed of to the last minute. The thermometer might descend below zero, ink might freeze, mirrors might crack; but, provided the stars shone, he and his sister worked on from dusk to dawn. . . . On one occasion he is said to have worked without intermission at the telescope and the desk for seventy-two hours."

Honours were showered on Herschel. He was knighted in 1816, and became President of the Royal Astronomical Society in 1820, besides receiving several honorary degrees. But honours in no way elated him. Advancing years in no way affected his wonderful mind. But his duties as King's Astronomer necessitated his acting as "showman of the heavens" on the visits of

royalties to Windsor, often after a whole day's work, when rest was absolutely necessary. This tremendous strain, which reflects little credit on the Court, proved too much for the old man. His health began to give way, although his mind was as vigorous as ever.

Herschel contributed his last paper to the Royal Society in 1818, and three years later sent a list of double stars to the new Astronomical Society. He made his last observation on June 1, 1821. His strength had now left him, and to this he could not reconcile himself. As Miss Clerke puts it, "All his old instincts were still alive, only the bodily power to carry out their behests was gone. An unparalleled career of achievement left him unsatisfied with what he had done. . . . His strong nerves were at last shattered." After a prolonged period of failing health he died at Slough, at the age of eighty-three, on August 25, 1822. On September 7 he was buried in the churchyard of St Laurence at Upton. On his tombstone are engraved the words—"Cœlorum perrupit claustra"—he broke through the barriers of the skies.

The death of her brother was a terrible blow to Caroline Herschel. Expecting to live only a twelvemonth, she returned to Hanover to

the home of her brother, Dietrich Herschel. But she lived twenty-five years among people who cared nothing for astronomy. She was delighted at Sir John Herschel's continuation of his father's work. She compiled a catalogue of all the clusters and nebulæ observed by her brother, for which she received the gold medal of the Astronomical Society, and she was created an honorary member. In 1846 she received from the King of Prussia the gold medal of science. But no honours made her in any way elated. She always held that whoever said much of her said too little of her brother. After a prolonged decline of health, she died on January 9, 1848, aged ninety-seven years, and was buried beside her father in the churchyard of the Gartengemeinde at Hanover, leaving behind her a noble example of self-sacrifice and devotion.

CHAPTER II.

HERSCHEL THE DISCOVERER.

One result of Herschel's discoveries among the stars and nebulæ is that his studies of the Sun and planets, with the exception of the discovery of Uranus, have been completely thrown into the shade. Nevertheless, his work in solar and planetary astronomy alone would have gained for him a higher position in astronomy than his contemporaries. The planets, satellites, and comets were all attentively studied by the great astronomer; indeed, the scientific investigation of the surfaces of Mars and Saturn began with Herschel.

"His attention to the Sun," Miss Clerke truly remarks, "might have been exclusive, so diligent was his scrutiny of its shining surface." Sunspots were specially investigated by Herschel, who closely studied their peculiarities, regarding them as depressions in the solar atmosphere. He also paid much attention to the faculæ, but

could not observe them to the north and south of the Sun, thus proving their connection with the spots which are confined to the regions north and south of the equator. "There is all over the Sun a great unevenness," said Herschel, "which has the appearance of a mixture of small points of an unequal light; but they are evidently a roughness of high and low parts."

Herschel's solar observations were very valuable, and did much for our knowledge of the orb of day. His theory of the Sun's constitution — a development of the hypothesis put forward by *Alexander Wilson* (1714-1786), Professor of Astronomy in Glasgow—was, however, very far from the truth. This was almost the only instance in which Herschel was mistaken. He regarded the Sun as a cool, dark globe, "a very eminent, large, and lucid planet, evidently the first, or, in strictness of speaking, the only primary one of our system." In his opinion an extensive atmosphere surrounded the Sun, the upper stratum forming what Schröter named the "photosphere." This atmosphere, estimated as two or three thousand miles in depth, was regarded as giving out light and heat. Below this shining atmosphere there existed, Herschel believed, a region of clouds protecting the globe of the Sun from the

glowing atmosphere, and reflecting much of the light intercepted by them. The spots were believed to be openings in these atmospheres, caused by the action of winds, the umbra or dark portion of the spot thus representing the globe of the Sun, which Herschel believed to be "richly stored with inhabitants." This theory held its ground for many years. Newton, it is true, believed the Sun to be gaseous, but he propounded no hypothesis of its constitution. Herschel's theory, on the other hand, was fully developed, plausible, and attractive. It was held by eminent men of science until 1860, when the revelations of the spectroscope showed it to be quite untenable. The theory was supported for many years by Sir John Herschel, who, however, abandoned it in 1864. Herschel made several attempts to ascertain whether any connection existed between the state of the Sun and the condition of the Earth. In 1801 he was inclined to believe that "some temporary defect of vegetation" resulted from the absence of sun-spots, which, he thought, "may lead us to expect a copious emission of heat, and, therefore, mild seasons." Herschel believed, in fact, that food became dear at the times of spot-minima. It may be remarked that Herschel never noted the spot-

period of eleven years, the discovery of which was afterwards made by Schwabe.

Herschel closely scrutinised the surfaces of the planets. Mercury alone was neglected by him. From 1777 to 1793 he observed Venus, with the object of determining the rotation period, but he was unable to observe any markings on the surface of the planet. He did not place reliance on Schröter's value of the rotation period (about twenty-three hours). Meanwhile, Schröter announced the existence on Venus of mountains which rose to five or six times the height of Chimborazo. As to these, said Herschel, "I may venture to say that no eye which is not considerably better than mine, or assisted by much better instruments, will ever get a sight of them." Herschel demonstrated the existence of an extensive atmosphere round Venus.

"The analogy between Mars and the Earth," Herschel wrote in 1783, "is perhaps by far the greatest in the whole Solar System." In 1777 he began, in his house at Bath, a series of observations on the red planet, which yielded results of the utmost importance. Fixing his attention on the white spots at the north and south poles,—discovered by Maraldi, nephew of Cassini,—he soon ascertained the fact that they

waxed and waned in size, the north polar cap shrinking during the summer of the northern hemisphere, increasing in winter, and *vice versa* in the southern hemisphere. He regarded the caps as masses of snow and ice deposited from "a considerable, though moderate, atmosphere," a theory now generally accepted. Herschel gave an immense impetus to the study of Mars. He carefully examined the planet's surface, and the dark markings were regarded by him as oceans.

During Herschel's lifetime the four small planets, Ceres, Pallas, Juno, and Vesta, were discovered by Piazzi, Olbers, and Harding. The great astronomer was much interested in these small worlds. He commenced a search through the Zodiacal constellations for new planets, but failed. He was of opinion that many minor planets would be discovered. Accepting Olbers' theory of the disruption of a primitive planet, Herschel calculated that Mercury might be broken up into 35,000 globes equal to Pallas. Meanwhile Herschel named the four new planets "Asteroids," owing to their minute size. He estimated the diameter of Ceres at 162 miles and Pallas at 147 miles, but Professor Barnard's measures have shown them to be larger.

In connection with the discovery of the Asteroids, Herschel showed a very fine spirit.

In 'The Edinburgh Review' Brougham declared that Herschel had devised the word "asteroid," so that the discoveries of Piazzi and Olbers might be kept on a lower level than his own discovery of Uranus. Many scientists would have been much offended at this contemptible insult, but Herschel merely remarked that he had incurred "the illiberal criticism of 'The Edinburgh Review,'" and that the discovery of the Asteroids "added more to the ornament of our system than the discovery of another planet could have done."

In Herschel's time astronomers were acquainted with three of the outer planets,—Jupiter, Saturn, and Uranus,—all of which were closely studied by the great astronomer. The belts of Jupiter were supposed by him to be analogous to the "trade-winds" in the atmosphere of the Earth; while the drifting-spots on Jupiter's disc and their irregular movements were carefully noted. His observations on the four satellites of Jupiter led him to believe that, like our Moon, they rotated on their axes in a period equal to that of their revolution round their primary — an opinion shared by Laplace, and by many modern astronomers.

Herschel's researches regarding Saturn were, however, much more important than those on

Jupiter. The globe of the planet, the rings and the satellites, were favourite objects of study at Bath and Slough. In 1794 he perceived a spot on the surface of Saturn, and made the first determination of the rotation of the planet, which he fixed as 10 hours 16 minutes,—a result confirmed by modern astronomers. The rings were subjected to the closest scrutiny. Herschel believed them to be solid, and he also considered them to revolve round Saturn in about 10 hours. It appears that he observed the famous "dusky ring," but supposed it to be a belt on the surface of the planet. He also studied Cassini's division in the ring, ascertaining its reality.

On completing his famous 40-foot reflector, Herschel, on August 28, 1789, turned it on Saturn and its five known satellites. Near the planet, and in the plane of the ring, was seen another object, which Herschel believed to be a sixth satellite. To settle the question, he watched the planet for several hours to see if the object would partake in the planet's motion. Finding that it did, he announced it as a new satellite, which he found to revolve round Saturn in 1 day 8 hours. About three weeks later, on September 17, Herschel discovered another satellite yet closer to Saturn, revolving

round the planet in about 22 hours. These two satellites were not seen by any astronomers except Herschel; and after his death they could not be observed. His son, however, rediscovered them.

The eighth satellite, Japetus, was shown by Herschel to rotate on its axis in a period equal to that of its revolution, and his observations were confirmed by modern observers. "I cannot," Herschel said, "help reflecting with some pleasure on the discovery of an analogy which shows that a certain uniform plan is carried on among the secondaries of our Solar System; and we may conjecture that probably most of the satellites are governed by the same law." In April 1805 Herschel observed the globe of Saturn to present not a spherical but a "square-shouldered" aspect. It was for long believed that this was an optical illusion; but Proctor and others have shown that it is quite possible for storms in Saturn's atmosphere to cause the planet's apparent distortion in shape.

Herschel paid much attention to the planet Uranus, which he discovered on March 13, 1781. The discovery of Uranus, which was mentioned in a previous chapter, was in a sense the most striking of Herschel's achievements. Uranus was the first planet discovered within the memory

of man: besides, the discovery enlarged the diameter of the Solar System from 886 to 1772 millions of miles. Throughout his lifetime Herschel referred to the planet as the "Georgium Sidus," out of gratitude to George III. for appointing him King's Astronomer; but the astronomers of France and Germany, who, as Sir Robert Ball remarks, "saw no reason why the King of England should be associated with Jupiter and Saturn," opposed this term. Lalande called the planet "Herschel," but Herschel's countrymen, the Germans, named it Uranus, in keeping with the custom of designating the planets from the Greek mythology. The name of Uranus ultimately prevailed.

In January 1787 Herschel discovered two satellites to Uranus, with the aid of his 20-foot telescope. These satellites he believed to revolve round Uranus in 8 days and 13 days respectively, and accordingly he made a drawing of what their positions should be on February 10. On that day he found them in their predicted places. In 1797 he announced that the satellites revolved round Uranus in orbits at right angles to the ecliptic, and in a retrograde direction. In subsequent years Herschel believed that he had discovered other four satellites to Uranus, but he was unable

to confirm his belief. As Mr Gore says, some of the satellites "must, therefore, have been either optical 'ghosts' or else small fixed stars which happened to be near the planet's path at the time of observation. Herschel also suspected that he could see traces of rings round Uranus like those round Saturn, but his observation was never confirmed, either by himself or other observers."

Although Herschel made several important observations on the Moon, and measured the heights of the lunar mountains, he was not a devoted student of our satellite. Caroline Herschel remarks in her memoirs that if it had not been for clouds or moonlight, neither her brother nor herself would have got any sleep; adding that Herschel on the moonlight nights prepared his papers or made visits to London. However, he did make some investigations, and in 1783 and 1787 believed himself to have witnessed the eruption of three lunar volcanoes. He afterwards concluded, however, that what he believed to be eruptions was really the reflexion of earth-shine from the white peaks of the lunar mountains. Herschel never discovered a comet, leaving that branch of astronomy to his sister, who discovered eight of these objects. He was, however, much in-

terested in comets, and attentively studied them, introducing the terms of "head," "nucleus," and "coma." Herschel anticipated the view that comets are not lasting, but are partly disintegrated at their perihelion passages. He was of opinion that they travelled from star to star. The extent of their tails and appendages he thought to be a test of their age.

We have now completed our sketch of Herschel's important labours regarding our Solar System. As Miss Clerke says, "A whole cycle of discoveries and successful investigations began and ended with him." But through observing the stars he made a further discovery in connection with the Solar System; indeed, one of the greatest discoveries in the history of astronomy—the movement through space of the Sun, carrying with it planets and comets.

"If the proper motion of the stars be admitted," said Herschel, "who can deny that of our Sun?" Of course it was plain that the motion of the Sun could only be detected through the resulting apparent motion of the stars. Thus, if the Sun is moving in a certain direction, the stars in front will appear to open out, while those behind will close up. But the problem is by no means so easy as this. The stars are also in motion, and, before the solar

motion can be discovered, the proper motions of the stars—themselves very minute—have to be decomposed into two parts, the real motion of the star, and the apparent motion, resulting from the movement of the Solar System. To any astronomer but Herschel the problem would have been insoluble. Only sixty years had elapsed since Halley had announced the proper motions of the brighter stars which had been previously supposed to be immovable — hence the name of "fixed stars." Herschel did not deal with the motions of many stars. Only a few proper motions were known with accuracy when he attacked the problem in 1783. Making use of the proper motions of seven stars, and separating the real from the apparent motion, he found that the Solar System was moving towards a point in the constellation Hercules, the "apex" being marked by the star λ Herculis. The rate of the solar motion, Herschel thought, was "certainly not less than that which the Earth has in her annual orbit." This extraordinary discovery was one of Herschel's greatest works. "Its directness and apparent artlessness," Miss Clerke remarks, "strike us dumb with wonder." In 1805 Herschel again attacked the subject, utilising the proper motions of thirty-six stars. His second inquiry, on the

whole, confirmed his previous result, the "apex" being again situated in Hercules; but the determination of 1783 was probably the more accurate of the two.

Herschel was far in advance of his time regarding the solar motion. The two greatest astronomers of the next generation, Bessel and Sir John Herschel, rejected the results reached by Sir William Herschel. But in 1837 Argelander, after a profound mathematical discussion, confirmed Herschel's views, and proved the solar motion to be a reality. Since that date the problem has been attacked by various methods by Otto Struve, Gauss, Mädler, Airy, Dunkin, Ludwig Struve, Newcomb, Kapteyn, Campbell, and others, with the result that the reality of the solar motion and of the direction fixed by Herschel has been proved beyond a doubt. As Sir Robert Ball well remarks, mathematicians have exhausted every refinement, "but only to confirm the truth of that splendid theory which seems to have been one of the flashes of Herschel's genius."

In his volume 'Herschel and his Work,' Mr James Sime writes: "To Herschel belongs the credit not merely of having suspected the revolution of sun around sun in the far-distant realms of space, but also of actually detecting that this

was going on among the stars." Throughout his career double stars were favourite objects of observation. The study of double stars was commenced by Herschel while a musician in Bath. Before his day, of course, double stars had been discovered and studied, but it was believed that the proximity of two stars was merely an optical accident, the brighter star being much nearer to us than the other. Herschel, at first sharing the general view, observed double stars in the hope of measuring their relative parallaxes; assuming one star to be much farther away from the Solar System than another, he attempted to measure the parallactic displacement of the brighter star relatively to the position of the fainter. "This," he afterwards wrote, "introduced a new series of observations. I resolved to examine every star in the heavens with the utmost attention, that I might fix my observations upon those that would best answer my end. I took some pains to find out what double stars had been recorded by astronomers; but my situation permitted me not to consult extensive libraries, nor, indeed, was it very material; for as I intended to view the heavens myself, Nature, that great volume, appeared to me to contain the best catalogue."

Herschel, on January 10, 1782, submitted to the Royal Society a catalogue of 269 double

stars: of these he himself discovered 227. In December 1784 he forwarded another catalogue, containing 434 stars. He soon found that he was unable to measure stellar parallax, and the idea dawned on him that the double stars were physically connected by the law of gravitation, though he made no announcement to that effect for many years. On July 1, 1802, Herschel informed the Royal Society that "casual situations will not account for the multiplied phenomena of double stars. . . . I shall soon communicate a series of observations, proving that many of them have already changed their situation in a progressive course, denoting a periodical revolution round each other." In 1803 he showed that many stars were revolving round their centres of gravity, proving them, in his own words, to be "intimately held together by the bond of mutual attraction." In other words, Herschel discovered that the law of gravitation prevailed in the Stellar Universe, as well as in our Solar System—that the law which Newton ascertained to prevail in the Solar System extended throughout the depth of space.

Herschel did not merely prove the revolution of the binary stars; he assigned periods to those which he had particularly studied. He believed the period of Castor to be 342 years;

γ Leonis 1200 years; δ Serpentis 375 years; and ϵ Böotis 1681 years. Herschel did not compute the orbits mathematically. This was not done for nearly thirty years, when the calculation of binary star-objects was commenced by Savary, Sir John Herschel, and Encke.

In 1782 the French astronomer, *Charles Messier* (1730-1817), published a list of 103 nebulæ. In the following year Herschel commenced his famous sweeps of the heavens with his large reflectors, and during these he made many remarkable discoveries. In 1786 he published in the 'Philosophical Transactions' of the Royal Society a catalogue of a thousand new nebulæ and star-clusters, in which he gave the position of each object with a short description of its appearance, written by Caroline Herschel while her brother actually had the object before his eyes. In 1786 Herschel published a catalogue of another thousand clusters and nebulæ, followed in 1802 by a list of 500; making a total of 2500 clusters and nebulæ discovered by the great astronomer. This alone would have gained a great name for William Herschel in this branch of astronomy. In the space of only twenty years 2500 nebulæ and clusters had been discovered. The various nebulæ and clusters were divided into eight classes, as follows: the

first class being "bright nebulæ," the second "faint nebulæ," the third "very faint nebulæ," the fourth "planetary nebulæ," so named by Herschel from their resemblance to planetary discs, the fifth class contained "very large nebulæ," the sixth "very compressed and rich clusters of stars," the seventh "pretty much compressed clusters of large or small stars," and the eighth "coarsely scattered clusters of stars."

At first Herschel believed all nebulæ to be clusters of stars, the irresolvable nebulæ being supposed to be farther from our system than the resolvable nebulæ. As many of the nebulæ which Messier could not resolve had yielded to Herschel's instruments, Herschel believed that increase of telescopic power would resolve the hazy spots of light which remained nebulous. In the paper of 1785, in which Herschel dealt with the construction of the heavens, he stated his belief that many of the nebulæ were external galaxies—universes beyond the Milky Way; and in 1786 he remarked that he had discovered fifteen hundred universes!

Arago, Mitchel, Nichol, Chambers, and other writers quite misinterpreted Herschel's views on the nebulæ when they said that he believed them to be all external galaxies. In 1785

Herschel believed many to be connected with the sidereal system; considering that in some parts of the Galaxy "the stars are now drawing towards various secondary centres, and will in time separate into different clusters." He was coming to the view that the star-clusters were secondary aggregations within the Galaxy, probably the true theory. He pointed out that in Scorpio, the cluster Messier 80 is bounded by a black chasm, four degrees wide, from which he believed the stars had been drawn in the course of time to form the cluster. His sister records that one night, after a "long, awful silence," he exclaimed on coming on this chasm —"Hier ist wahrhaftig ein Loch im Himmel!" (Here, truly, is a hole in the heavens.)

Herschel was now gradually giving up his theory of external galaxies and his "disc-theory" of the Universe; but he still believed even the nebulous objects to be irresolvable only through immensity of distance. In 1791, however, he drew attention to a remarkable star in Taurus, surrounded by a nebulous atmosphere, regarding which he wrote, "View, for instance, the nineteenth cluster of my sixth class, and afterwards cast your eye on this cloudy star. Our judgment, I will venture to say, will be that *the nebulosity about the star is not of a starry*

nature. We therefore either have a central body which is not a star, or have a star which is involved in a shining fluid, of a nature totally unknown to us." And with caution he added that "the envelope of a cloudy star is more fit to produce a star by its condensation than to depend upon the star for its existence."

This was written in 1791, five years before Laplace propounded his nebular theory. Meanwhile Herschel, believing that "these nebulous stars may serve as a clue to unravel other mysterious phenomena, found that the theory of a "shining fluid" would suit the appearance of the irresolvable planetary nebulæ and the great nebula in Orion much better than the extravagant idea of "external universes." Herschel now considered the Orion nebula to be much nearer to the Solar System than he formerly did, and ceased to regard it as external to the Galaxy. For twenty years Herschel patiently observed the nebulæ, and it was not until 1811 that he propounded his nebular hypothesis of the evolution of the Sun and stars. He found the gaseous matter in all stages of condensation, from the diffused cloudy nebulæ like that in Orion, through the planetary nebula and the regular nebula, to the perfect stars, like Sirius and the Sun. Herschel's nebular theory

was a grand conception, and a magnificent attack on the secrets of nature.

Sir Robert Ball says: "Not from abstract speculation like Kant, nor from mathematical suggestion like Laplace, but from accurate and laborious study of the heavens, was the great William Herschel led to the conception of the nebular theory of evolution." Herschel's nebular theory was wider and less rigorous than that of Laplace. Laplace reached his theory by reasoning backwards; Herschel by observing the nebulæ in process of condensation. Consequently, while Laplace's theory has required modification, Herschel's, from its width, is universally accepted, because there is nothing mathematically rigorous in it. The great German did not go into details like his French contemporary. He sketched the evolution of the stars in a wider sense.

The astronomer's "1500 universes," Miss Clerke remarks, "had now logically ceased to exist." Herschel had gathered much evidence about nebular distribution which shattered his belief in external universes, although he still thought in 1818 that some galaxies were included among the non-gaseous nebulæ. In 1784 Herschel pointed out that the clusters and nebulæ "are arranged to run in strata"; and some time later

he found that the nebulæ were aggregated near the galactic poles; in other words, where nebulæ are numerous, stars are scarce, and *vice versa*. So rigorously did this rule hold, that when dictating his observations to his sister Caroline, he would, on noting a paucity of stars, warn her to "prepare for nebulæ."

"A knowledge of the construction of the heavens has always been the ultimate object of my observations." So Herschel wrote in 1811. All his investigations were secondary to the problem which was constantly before his mind —the extent and structure of the Universe. He aspired to be the Copernicus of the Sidereal System. Although Bruno, Kepler, Wright, Kant, and Lambert had speculated regarding the construction of the heavens, they had not the slightest evidence on which to base their ideas. There was no science of sidereal astronomy. The stars were observed only to assist navigation, and the primary object of star-catalogues was to further knowledge of the motions of the planets. In Herschel's day, also, the distances of the stars had not been measured, and he had to base his views on the distribution of the stars. In 1784, therefore, he commenced a survey of the heavens, in order to ascertain the number of stars in various parts of the sky. This method, which

he named "star-gauging," consisted in counting the number of stars in the telescopic field. Totally he secured 3400 gauges. His studies showed that in the region of the Galaxy the stars were much more numerous than near the galactic poles. Sometimes he saw as many as 588 stars in a telescopic field, at other times only 2. He remarked that he had "often known more than 50,000 pass before his sight within an hour." Assuming that the stars were, on the average, of about the same size, and scattered through space with some approach to uniformity, Herschel was unable to compute the extent to which his telescope penetrated into space; and, assuming that the Universe was finite and that his "gauging-telescope" was sufficiently powerful to completely resolve the Milky Way, he was enabled to sketch the shape and extent of the Universe.

Thus Herschel concluded that the Universe extended in the direction of the Galaxy to 850 times the mean distance of stars of the first magnitude. In the direction of the galactic poles the thickness was only 155 times the distance of stars of the same magnitude. Herschel was thus enabled to sketch the probable form of the Universe, which he regarded as cloven at one of its extremities, the cleft being represented

by the famous gap in the Milky Way. The Universe was, in fact, supposed to be a cloven disc, and the Milky Way was merely a vastly extended portion of it and not a region of actual clustering. On this theory the clusters and nebulæ were supposed to be galaxies external to the Universe. Even in 1785, however, Herschel believed that there were regions in the Milky Way where the stars were more closely clustered than others. "It would not be difficult," he wrote in 1785, "to point out two or three hundred gathering clusters in our system."

Strange to say, Herschel's original ideas regarding the Universe were accepted for many years by astronomical writers. Arago accepted Herschel's original theory, unaware that he had in reality abandoned it, and he was followed by a host of French and English writers who did not take the trouble to read each of Herschel's papers, merely quoting that of 1785, and believing that it represented his final ideas on the subject. Even Sir John Herschel seems to have been unaware that his father gave up the disc theory of the Universe. The famous German astronomer, Wilhelm Struve, after an exhaustive study of Herschel's papers, was enabled to prove in 1847 that the theory had been abandoned

by Herschel; and in England the late R. A. Proctor independently demonstrated the same thing. Meanwhile, supposing Herschel had not given up his theory, it would be quite untenable. After considering the fact that the brighter stars, down to the ninth magnitude, aggregate on the Milky Way, Mr Gore says: "As the stars are by hypothesis supposed to be uniformly distributed throughout every part of the disc, and as the limiting circles for stars to the eighth and ninth magnitudes fall well within the thickness of the disc, there is no reason why stars of these magnitudes should not be quite as numerous in the direction of the galactic poles as in that of the Milky Way itself. We see, therefore, that the disc theory fails to represent the observed facts, and that Struve and Proctor were amply justified in their opinion that the theory is wholly untenable, and should be abandoned."

The observations made by Herschel himself eventually proved fatal to the disc theory—a hypothesis which he had all along held very lightly. His ideas about subordinate clusters within the Milky Way were soon confirmed, and though in 1799 he still adhered to the disc theory, he wrote in 1802, "I am now convinced, by a long inspection and continued examination of it, that the Milky Way itself consists of stars

very differently scattered from those which are immediately about us. This immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered"—a conclusion quite opposed to the disc theory, where the Milky Way was supposed to be merely an extended portion of the Universe.

In 1811 Herschel wrote as follows: "I must freely confess that by continuing my sweeps of the heavens, my opinion of the arrangement of the stars, and their magnitudes, and some other particulars, has undergone a gradual change; and, indeed, when the novelty of the subject is considered we cannot be surprised that many things formerly taken for granted should on examination prove to be different from what they were generally but incautiously supposed to be. For instance, an equal scattering of the stars may be admitted in certain calculations; but when we examine the Milky Way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, this supposed equality of scattering must be given up."

This was the virtual abandonment of the disc theory. Six years later Herschel announced that in six cases he had failed to resolve the

Milky Way, stating that his telescopes could not fathom it. This was the abandonment of his second assumption—namely, that his telescope was sufficiently powerful to penetrate to the limits of the Universe. Yet he still thought that some of the star-clusters might be external galaxies, although he could not even dogmatically assert our Universe to be limited. In an error of translation, Struve left the impression that Herschel believed our Universe to be unfathomable or infinite, and was obliged to devise a most artificial theory of the extinction of light to account for the fact that the sky did not shine with the brilliance of the Sun, which it would do were the stars infinite in number. Of course, Herschel did not actually believe the Universe to be infinite, and, had he lived, he would probably have shown that all the star-clusters which we see are included within the bounds of our finite Galaxy.

In 1814 Herschel was "still engaged in a series of observations for ascertaining a scale whereby the extent of the Universe, as far as it is possible for us to penetrate into space, may be fathomed." In 1817 he described another method of star-gauging, which Arago and other writers have confused with that which he devised in 1785. The two methods, however, were quite

distinct from each other. In the first system, one telescope was used on different regions of the heavens; whereas in the second method, various telescopes were used on identical regions. The principle was that the telescopic power necessary to resolve groups of stars indicates the distance at which the stars of the groups lie. This, however, also assumed an equal distribution of stars, and as the late Mr Proctor says, "I conceive that no question can exist that the principle is unsound, and that Herschel would himself have abandoned it had he tested it earlier in his observing career. . . . In applying it, Sir W. Herschel found regions of the heavens very limited in extent, where the brighter stars (clustered like the fainter) were easily resolved with low powers, but where his largest telescopes could not resolve the faintest. These regions, if the principle were true, must be long, spike-shaped star groups, whose length is directed exactly towards the astronomer on Earth,—an utterly incredible arrangement."

Herschel, at the time of his death, left unsolved the problem of the construction of the heavens. It is still unsolved, and will doubtless remain so until astronomers know more about the distances and motions of the stars. His last observation of the Galaxy showed that even

with his 40-foot reflector he could not fathom it. Consequently, as we have mentioned, Struve and his successors regarded the Universe as infinite—a theory which has now received its death-blow. Herschel was undoubtedly correct when he stated his belief in a limited Universe.

Herschel's star-gauges, and those of his son, still remain of immense value to astronomers in any discussion of the construction of the heavens. Thus, although they failed to reveal to Herschel the structure of the Universe, they have been of much use to his successors. Herschel's discussion of the supreme problem—the ultimate object of his observations—constitutes one of the most interesting chapters in the history of science, and marks a new era in human thought. In the words of Miss Clerke: "One cannot reflect without amazement that the special life-task set himself by this struggling musician—originally a penniless deserter from the Hanoverian Guard—was nothing less than to search out the 'construction of the heavens.' He did not accomplish it, for that was impossible; but he never relinquished, and, in grappling with it, laid deep and sure the foundations of sidereal science."

CHAPTER III.

THE SUN.

FOUR years after the death of Herschel, an apothecary in the little German town of Dessau procured a small telescope, with which he began to observe the Sun. The name of this apothecary was *Samuel Heinrich Schwabe* (1789-1875). In 1826 he commenced to observe the spots on the Sun's disc, counting them from day to day, more for self-amusement than from any hope of discovery; for previous astronomers had agreed that no law regulated the number of the sun-spots. Every clear day Schwabe pointed his telescope at the Sun and took his record of the spots; this he continued for forty-three years, until within a few years of his death on April 11, 1875. As early as 1843 Schwabe hinted that a possible period of ten years regulated the distribution of the spots on the Sun, but no attention was given to his idea. In 1851, however, the result of his twenty-six

years of observation was published in Humboldt's 'Cosmos,' and Schwabe was able to show that the spots increased and decreased in a period of about ten years. Astronomers at once recognised the importance of Schwabe's work, and in 1857 he was rewarded by the Gold Medal of the Royal Astronomical Society of London.

Rudolf Wolf (1813-1892) of the Zürich Observatory now undertook to search through the records of sun-spot observation, from the days of Galileo and Scheiner, to find traces of the solar cycle discovered by Schwabe. He was successful, and was enabled to correct Schwabe's estimate of the length of the period, fixing it as on the average 11·11 years. Additional interest, however, was given to Schwabe's and Wolf's investigations by the remarkable discoveries which followed. In September 1851 *John Lamont* (1805-1879), a Scottish astronomer,—born at Braemar in Aberdeenshire, but employed as director of the Munich Observatory,—after searching through the magnetic records collected at Göttingen and Munich, discovered that the magnetic variations indicated a period of 10½ years. Soon after this Sir *Edward Sabine* (1788-1883), the English physicist, from a discussion of an entirely different set of observations, independently demonstrated the same

thing, proving conclusively that once in about ten years magnetic disturbances reached their height of violence; and Sabine was not slow to notice the correspondence between the magnetic period and the sun-spot period. In the same year (1852) Wolf and *Alfred Gautier* (1793-1881) independently made the same discovery, which had thus been made by four separate investigators.

In the same year an English amateur astronomer, *Richard Christopher Carrington* (1826-1875), commenced a series of solar observations which led to some remarkable discoveries. From observations on the spots, Carrington discovered that while the Sun's rotation was performed in 25 days at the equator, it was protracted to 27½ days midway between the equator and the poles. In 1858 Carrington demonstrated the fact that spots are scarce in the vicinity of the solar equator, but are confined to two zones on either side, becoming scarce again at thirty-five degrees north or south of the equator. Contemporary with Carrington was *Friedrich Wilhelm Gustav Spörer* (1822-1895), who was born in Berlin in 1822 and died at Giessen, July 7, 1895. He commenced his solar observations about the same time as Carrington, and independently discovered the Sun's equatorial

acceleration. From observations at his little private observatory at Anclam in Pomerania, continued at the Astrophysical Observatory in Potsdam, Spörer demonstrated a remarkable law regarding sun-spots. This law is thus described by a well-known astronomer: "The disturbance which produces the spots of a given sun-spot period first manifests itself in two belts about thirty degrees north and south of the Sun's equator. These belts then draw in toward the equator, and the sun-spot maximum occurs when their latitude is about sixteen degrees; while the disturbance gradually and finally dies out at a latitude of eight or ten degrees. Two or three years before this disappearance, however, two new zones of disturbance show themselves. Thus, at the sun-spot minimum there are four well-marked spot-belts,—two near the equator, due to the expiring disturbance, and two in high latitudes, due to the newly beginning outbreak." These remarkable discoveries, which resulted from the investigations of Schwabe, Carrington, and Spörer, are a brilliant example of what may be done by amateurs in astronomy.

At the time when Carrington and Spörer were pursuing these researches, the spectroscope came into use as an astronomical instrument, and since 1859 solar astronomy has been almost entirely

spectroscopic. Before we can rightly understand the principles of spectroscopic astronomy, we must go back to the life and work of its founder—Joseph von Fraunhofer.

The son of a poor glazier, *Joseph von Fraunhofer* was born on March 6, 1787, at Straubing, in Bavaria. His father and mother having died when their son was quite young, the boy, on account of his poverty, was apprenticed to a looking-glass manufacturer in Munich named Weichselberger, who acted tyrannically, keeping him all day at hard work. Still the lad borrowed some old books, and spent his nights in study. Young Fraunhofer lodged in an old tenement in Munich, which on July 21, 1801, collapsed, burying in its ruins its occupants. All were killed but Fraunhofer, who, though seriously injured, was dug out from the ruins four hours later. The distressing accident was witnessed by Prince Maximilian Joseph, Elector of Bavaria. He became interested in Fraunhofer, and presented him with a sum of money. Of this he made good use. He was already interested in optics, and he bought some books on that subject, as well as a glass-polishing machine. The remainder of the money served to procure his release from his tyrannical master, Weichselberger.

Fraunhofer became acquainted with prominent

scientists at Munich, who provided him with books on optics and mathematics. Meanwhile the young optician occupied his time in shaping and finishing lenses. In 1806 he entered the optical department of the Optical and Physical Institute of Munich, and the following year, when only twenty years of age, was appointed to the chief post in that department. In 1814 he commenced his investigations with the prism, which have made his name famous.

Newton had found that, in passing through a prism, white light is dispersed into its primary colours, making up the band of coloured light known as the solar spectrum. But he failed to recognise the existence of dark lines in the spectrum. Casually seen in 1802 by *William Hyde Wollaston* (1786-1828), an English physicist, these lines were first thoroughly examined by Fraunhofer. Allowing light from the Sun to pass through a prism attached to the telescope, he was amazed to find several dark lines in the spectrum. By the year 1814 he had detected no less than 300 or 400 of these lines. Fraunhofer named the more prominent lines by the letters of the alphabet, from A in the red to H in the violet. They are now known as the Fraunhofer lines. At first he was much perplexed regarding the nature of the dark lines.

He suspected that they might be an optical effect, depending on the quality of the glass used, and he tried different prisms, but the lines were still to be seen. Then he turned his prism to bright clouds to see if they were visible in reflected sunlight, and he found that they were. He examined the Moon and again perceived them, as moonlight is merely reflected sunlight; and they were also conspicuous in the spectra of the planets. It was thus proved that these lines were characteristic of sunlight, whether direct or reflected. It was, however, still possible that they might be caused by the passage of the rays of light from the celestial bodies through the Earth's atmosphere. In order to test this theory, Fraunhofer examined the spectra of the brighter stars. He found that the lines visible in the solar spectrum were not to be seen in the spectra of the stars, thus proving that the lines were not merely an atmospheric effect. Each star, Fraunhofer observed, had a different spectrum from both the Sun and from other stars. These spectra were also characterised by numerous dark lines, much fainter than those in the solar spectrum.

Although he ascertained the existence of the dark lines in the Sun's spectrum, Fraunhofer never really found out what they represented.

As Miss Giberne expresses it, "Although he now saw the lines he could not understand them: he could not read what they said. They spoke to him indeed about the Sun, but they spoke to him in a foreign language, the key to which he did not possess." However, he expressed the belief that the pair of lines in the solar spectrum, which he marked D, coincided with the pair of bright lines emitted by incandescent sodium. Although he doubtless suspected that the lines conveyed intelligence regarding the elements in the Sun, he never was able properly to decipher their meaning. Had he lived, he would probably have made the great discovery; but these investigations were cut short by his sudden and untimely death on June 7, 1826.

After the death of Fraunhofer, very little was done to forward the study of spectrum analysis. Investigations in this branch of research were made, however, by Sir *John Herschel* (1792-1871), *William Allen Miller* (1817-1870), Sir *David Brewster* (1781-1868), and others. Two famous men of science had partly discovered the secret. These were Sir *George Stokes* (1819-1903), of Cambridge, and *Anders John Angström* (1812-1872) of Upsala. Of Angström's work, published in 1853, it has been said that it would "have obtained a high

celebrity if it had appeared in French, English, or German, instead of Swedish."

It was not until 1859 that the principles of spectrum analysis were fully enunciated by *Gustav Robert Kirchhoff* (1824-1887), and his colleague in the University of Heidelberg, *Robert Wilhelm Bunsen* (1811-1899). Kirchhoff demonstrated that a luminous solid or liquid gives a continuous spectrum, and a gaseous substance a spectrum of bright lines. In the words of Miss Clerke, "Substances of every kind are opaque to the precise rays which they emit at the same temperature. That is to say, they stop the kinds of light or heat which they are then actually in a condition to radiate. . . . This principle is fundamental to solar chemistry. It gives the key to the hieroglyphics of the Fraunhofer lines. The identical characters which are written bright in terrestrial spectra are written dark in the unrolled sheaf of sun-rays." Kirchhoff made several determinations of the substances in the Sun, proving the existence of sodium, iron, calcium, magnesium, nickel, barium, copper, and zinc. His great map of the solar spectrum was published by the Berlin Academy in 1860, and represented an enormous amount of labour. It was succeeded by another map by Angström, published in 1868. But both of

these maps have been recently superseded by the investigations of Sir *Joseph Norman Lockyer* (born 1836), and of the American physicist, *Henry Augustus Rowland* (1848-1901). Rowland largely increased our knowledge of the elements in the solar atmosphere.

The spectroscope had become, by 1868, a recognised instrument of astronomical research, and in that year it was applied during the famous total eclipse, visible in India. There were many eclipse problems, arising from the observations made by the eclipse expeditions of 1842, 1851, and 1860. The eclipse of 1851 had finally proved that the red flames seen surrounding the Sun during total eclipses belonged to the Sun, and not to the Moon, as many astronomers had believed. At the eclipse of 1860, visible in Spain, the Italian astronomer, *Angelo Secchi* (1818-1878), and the Englishman, *Warren De la Rue* (1815-1889), secured photographs of the solar prominences. The problem of 1868 was the constitution of these prominences.

Pierre Jules César Janssen, born in Paris in 1824, was stationed at Guntoor, in India, to observe the eclipse. He succeeded in observing the spectrum of the prominences during the progress of totality, and found it to be one of bright lines, proving the gaseous nature of the

sun-flames. During the progress of the eclipse, Janssen was specially struck by the brilliancy of the bright lines, and it occurred to him that the prominence-spectrum could be observed in full daylight, if sufficient dispersive power was used to enfeeble the ordinary continuous spectrum. At ten o'clock on the following morning, August 19, 1868, Janssen applied his spectroscope to the sun, and observed the prominence-spectrum. After a month's observation in India, he sent to the French Academy an account of his success. A short time, however, before his report arrived, the Academy had received a similar one from Lockyer, who had independently made the same discovery. Two years previously, in 1866, the new method had occurred to him, but his spectroscope was not powerful enough; and although he ordered a more powerful one at once, it was not until October 16, 1868, that he had the instrument in his hands. Four days later he observed the prominence-spectrum in full daylight.

The next advance in the study of the prominences was announced in 1869. Janssen and Lockyer had shown astronomers how to observe the spectrum of the prominences; but the researches of other two famous astronomers enabled observers to see the forms of the prominences.

These two men were *William Huggins* (born 1824) and *Johann Carl Friedrich Zöllner*. The latter astronomer, born in Leipzig in 1834, was one of the most successful students of the solar prominences. He was Professor of Astrophysics in the University of Leipzig, a position which he filled with success until his untimely death on April 25, 1882. Independently of Huggins, he found that by opening the slit of the spectroscope wider, the forms of the prominences themselves could be seen. The study of the prominences was at once taken up by the most famous solar observers: these were Huggins and Lockyer in England, Spörer and Zöllner in Germany, Janssen in France, Secchi, Respighi, and Tacchini in Italy, Young in America. To *Charles Augustus Young* (born 1834) we owe the careful study of individual prominences. On September 7, 1871, he observed the most gigantic outburst on the sun ever witnessed, fragments of an exploded prominence reaching a height of 100,000 miles: Young, also, made the first attempt to photograph the prominences.

To the Italian school of astronomers, however, we owe the persistent and systematic study of the prominences. Among them the three greatest names are *Angelo Secchi* (1818-1878),

Lorenzo Respighi (1824-1889), and *Pietro Tacchini* (1838-1905). After the death of Secchi, the recognised head of spectroscopy in Italy was Pietro Tacchini. Born at Modena in 1838, he was appointed director at Modena in 1859, assistant at Palermo in 1863, and director at Rome in 1879. In 1870 he commenced to take daily observations of the prominences, noting their sizes, forms, and distribution, and these observations were continued for thirty-one years, until within four years of Tacchini's death, which took place on March 24, 1905. Tacchini did for the study of the prominences what Schwabe did for the spots. The Italian spectroscopists found that the prominences increased and decreased every eleven years in harmony with the spots. Tacchini demonstrated that the streamers of the solar corona originate in regions where the prominences are most numerous, and that the shape of the corona, on the whole, varies in sympathy with the prominences.

The researches of Lockyer indicated that the prominences originated in a shallow gaseous atmosphere which he termed the chromosphere. Formerly astronomers had to observe only isolated prominences, but in 1892 an American astronomer, *George Ellery Hale* (born 1868), formerly director of the Yerkes Observatory,

and now director of the Solar Observatory in California, succeeded in photographing, by an ingenious process, the whole of the chromosphere, prominences, and faculæ visible on the solar surface.

Another solar envelope was discovered in 1870 by Dr Charles Augustus Young, who from 1866 to 1877 directed the Observatory at Dartmouth, New Hampshire, and from 1877 to 1905, that at Princeton, New Jersey. During the eclipse of December 22, 1870, Young was stationed at Tenez de Frontena, Spain. As the solar crescent grew apparently thinner before the disc of the Moon, "the dark lines of the spectrum," he says, "and the spectrum itself gradually faded away, until all at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with bright lines, more numerous than one could count. The phenomenon was so sudden, so unexpected, and so wonderfully beautiful, as to force an involuntary exclamation." The phenomenon was observed for two seconds, and the impression was left on the astronomer that a bright line had taken the place of every dark one in the solar spectrum, the spectrum being completely reversed. Hence the name which was given to the hypothetical envelope—"the reversing layer." For long the existence

of the reversing layer was disputed by numerous astronomers. In 1896 photographs taken during the solar eclipse of that year finally demonstrated the existence of the "flash spectrum" as seen by Young.

The last of the solar appendages, the corona, can only be seen during total eclipses. The researches of Young and Janssen indicate that it is partly gaseous and partly meteoric in its constitution; and various photographs, taken at the eclipses since 1870, have demonstrated its variation in shape, which is in harmony with the eleven-year period. Several attempts have been made to observe the corona without an eclipse. In 1882 Huggins made the attempt, but failed, and Hale, with his photographic process, had no better success. More recently, in 1904, a Russian astronomer, *Alexis Hansky*, observing from the top of Mont Blanc, secured some photographs on which he believes the corona is represented, but so far his observations have not been confirmed by other astronomers.

The application of the spectroscope to the motions on the solar surface is perhaps one of the most wonderful triumphs in astronomical science. In 1842 *Christian Doppler* (1803-1853), Professor of Mathematics at Prague, had ex-

pressed the view that the colour of a luminous body must be changed by its motion of approach or recession. It was obvious to Doppler that if the body was approaching, a larger number of light waves must be entering the eye of the observer than if it were retreating. Miss Clerke thus illustrates Doppler's principle: "Suppose shots to be fired at a target at fixed intervals of time. If the marksman advances, say, twenty paces between each discharge of his rifle, it is evident that the shots will fall faster on the target than if he stood still; if, on the contrary, he retires by the same amount, they will strike at correspondingly longer intervals." It occurred to various astronomers that it would be possible to measure cyclones and hurricanes in the Sun, not by change of colour in the spectrum, but by the shifting of the lines; and in 1870 this was successfully done by Lockyer. In the next few years efforts to measure the solar rotation were made by Young, Zöllner, and others, who succeeded in measuring the displacement of the lines, but not the time of rotation. This was reserved for the famous Swedish astronomer, Dunér.

Nils Christopher Dunér, born in 1839 in Scania, was employed as an assistant at Lund

Observatory from 1858 to 1888, when he was appointed director of the Observatory at Upsala. In that year he commenced a study of the solar rotation, measuring it by means of Doppler's principle. He confirmed the telescopic work of Carrington and Spörer on the equatorial acceleration, and measured the displacement up to within fifteen degrees of the poles. He brought out the surprising fact that the rotation period of the Sun is there protracted to $38\frac{1}{2}$ days. These remarkable researches were published in 1891.

In 1873 the Astronomer-Royal of England commenced at Greenwich Observatory to photograph the Sun daily. This work has been carried on there by *Edward Walter Maunder* (born 1851), and Greenwich Observatory possesses a photographic record of sun-spots. At the Meudon Astrophysical Observatory, near Paris, Janssen has, since 1876, secured photographs of the solar surface, which were comprised in a great atlas, published by him in January 1904. These photographs have revealed a remarkable phenomenon—the "réseau photospherique," the distribution over the solar surface of blurred patches of light, which Janssen considers are inherent in the Sun. The Greenwich records of sun-spots and of

magnetic disturbances have been made use of by Maunder in his remarkable studies, promulgated in 1904, of the connection between sun-spots and terrestrial magnetism. Maunder finds that on the average magnetic storms are dependent on the presence of sun-spots, and on the size of the spot. The magnetic action, he finds, does not radiate equally in all directions from the sun-spots, but along definite and restricted lines.

Herschel's hypothesis of a dark and cool globe beneath the solar photosphere was seen to be untenable after the introduction of the spectroscope. The first important theory as to the solar constitution was that advanced in 1865 by the French astronomer, *Hervé Faye* (1814-1902). Numerous other theories were afterwards advanced by Secchi, Zöllner, Young, and others, but a complete description of the various developments in solar theorising cannot be given here. There is no complete "theory" of the exact constitution of every part of the Sun, but the unpretentious "Views of Professor Young on the Constitution of the Sun," which appeared in April 1904 in 'Popular Astronomy,' represent the latest ideas of the foremost solar investigator. Professor Young regards the reversing layer and the chromosphere as "simply

the uncondensed vapours and gases which form the atmosphere in which the clouds of the photosphere are suspended." He says that the contraction theory of Helmholtz,—explained in another chapter,—advanced to explain the maintenance of the Sun's heat, is true so far as it goes; but that it is all the truth is now made doubtful by the discovery of radium, which "suggests that other powerful sources of energy may co-operate with the mechanical in maintaining the Sun's heat."

The important question of the distance of the Sun was thoroughly investigated in 1824 by *Johann Franz Encke* (1791-1865), then of Seeberg, near Gotha, who, from a discussion of the transits of Venus in 1761 and 1769, found a parallax of 8″·371, corresponding to a mean distance of 95,000,000 miles. This value was accepted for thirty years, until *Peter Andreas Hansen* (1795-1874), in 1854, and *Urban Jean Joseph Le Verrier* (1811-1877), in 1858, found from mathematical investigations that the distance indicated was too great. Preparations were accordingly made for the observation of the transits of Venus, which took place respectively on December 8, 1874, and December 6, 1882. On the first occasion many expeditions were sent to view the transit, consisting of

French, German, American, English, Scottish, Italian, Russian, and Dutch astronomers, and it was hoped that the solar parallax would be accurately measured once for all. However, the transit, although favoured with good weather, was not successful, owing to the difficulty of making exact measurements, by reason of the illumination and refraction in the atmosphere of Venus. Accordingly the values deduced for the parallax were far from unanimous. The transit of 1882 was not observed so extensively, as astronomers had found the transit of Venus to be by no means the best method. In 1877 Sir *David Gill* (born 1843), the great Scottish astronomer, determined the solar parallax successfully from measures of the parallax of Mars in opposition. His value was $8''{\cdot}78$, corresponding to 93,080,000 miles. Some years previous to this *Johann Gottfried Galle* (born 1812), the German astronomer, had, from measurements of the parallax of the asteroid Flora, deduced a solar parallax of $8''{\cdot}87$. Gill's work at the Cape in 1888, on the Asteroids, was successful in giving a more accurate value than the transit of Venus: in 1900 and 1901 measures of the parallax of the asteroid Eros, the nearest minor planet, were made by many different observatories, and agree with the other results. The

values which have been derived from the velocity of light, and from the constant of aberration, are fairly in agreement with those derived from direct measurement. On the whole, the most probable value of the parallax is about 8″·8, indicating a mean distance of about 92,700,000 miles, with a "probable error" of about 150,000 miles.

What a different picture the sun presents to us at the beginning of the twentieth century from that which it presented to Herschel and his contemporaries at the beginning of the nineteenth! To Herschel, the Sun was a cool dark globe, surrounded by a luminous atmosphere. As the outcome of the researches and discoveries outlined in this chapter, the Sun is now seen to be a vast central world, which is over a million times larger than the Earth. In the words of an able writer, "It is most probably a world of gases, where most of the metals and metallic bases that we know exist only as vapours, even at the Sun's surface, hotter than any furnace on earth, and getting a still fiercer heat for every mile of descent lower. Of that heat in the Sun's interior we can form no conception. The pressure within the Sun is equally inconceivable. A cannon-ball weighing 100 lb. on earth would weigh 2700

on the Sun. Thus a mighty conflict goes on unceasingly between imprisoned and expanding gases and vapours struggling to burst out, and massive pressures holding them down. For reasons we cannot fully understand, no equilibrium is reached. For millions of years uprushes and down-rushes of the white-hot materials have been proceeding on that bright photosphere which gives us light, and looks a picture of calm and quiescence. Above that is a comparatively thin rose-coloured layer, the chromosphere, agitated with fiery 'prominences,' and outside all these the coronal glory—all alike pointing to immeasurable activities."

The following remark of Professor Newcomb shows our inability to realise the solar activity. "Suppose," he says, "every foot of space in a whole country covered with 13-inch cannon, all pointed upward, and all discharged at once. The result would compare with what is going on inside the photosphere about as much as a boy's popgun compares with the cannon."

CHAPTER IV.

THE MOON.

It is somewhat remarkable that the one celestial body which Herschel neglected was our satellite, the Moon; and it is also remarkable that the Moon was for many years the chief object of study of his contemporary astronomer, *Johann Hieronymus Schröter* (1745-1816). Born at Erfurt, near Hanover, on August 30, 1745, Johann Hieronymus Schröter was originally intended for the study of law, for which he was sent to the University of Göttingen. At the same time he studied mathematics, and particularly astronomy, under the mathematician, Kaestner of Göttingen. Deeply interested in music, he became acquainted with the Herschel family, and, inspired by William Herschel's example, determined to study the heavens. In 1779 he became the possessor of a small achromatic refractor, and commenced to observe the Sun and Moon. In 1778 he entered the legal

profession at Hanover, and four years later he was appointed "oberamtmann" or Chief Magistrate of Lilienthal—"the Vale of Lilies"—in the Duchy of Bremen. At Lilienthal Schröter erected a small observatory, and acquired in 1785 one of Herschel's 7-foot reflectors. In 1792 the astronomer superintended the construction of a 13-foot reflector, made by Schrader of Kiel, who transferred his workshop to Lilienthal. With these instruments the great work of Schröter was accomplished.

Schröter directed his powers of observation to the study of the Moon. He originated the study of the surface of the Moon, and founded the branch of astronomy known as selenography, or the study of the Moon's surface. The foundations of this branch were laid in 1791 with the publication of Schröter's 'Selenotopographische Fragmente.' The astronomer determined to make a comparative study of the surface of our satellite, and before 1801 discovered eleven "rills" or clefts on the Moon's surface, and recognised a large number of craters. He likewise believed that he had seen a lunar atmosphere, an observation of which was made by him in February 1792. Schröter seems never to have doubted what Herschel and his contemporaries believed—that

the Moon was a living world with volcanoes in active eruption, surrounded by an atmosphere, and inhabited by beings like ourselves. Unfortunately, Schröter was not good at making drawings of what he saw; nevertheless, he accomplished a vast amount of work. In the little observatory at Lilienthal the foundations were laid of the comparative study of the surface of the Moon.

But these observations were destined to be rudely interrupted. In 1810 Hanover was occupied by the invading troops of Napoleon, and Schröter lost his appointment as Chief Magistrate of Lilienthal, and also his income. But there was worse to follow. On April 20, 1813, three years after, the French, under Vandamme, with that cruelty which seems to belong to warfare, occupied Lilienthal, and set fire to the little village. A few days later the French soldiers entered the observatory and burned it to the ground. All Schröter's precious observations, accumulated after thirty-four years' labour, were destroyed with a few exceptions, the observations on Mars narrowly escaping the conflagration. Unable to forget the destruction of his observatory, and without the means to repair the loss, he lived only three years after the disaster. He died on August 29, 1816, "leaving

behind him," says Mr Arthur Mee, "an imperishable record, and a noble example to observers of all time."

Wilhelm Gotthelf Lohrmann, a land-surveyor of Dresden, continued the observations of Schröter, and in 1824 published four of the twenty-five proposed sections of a large lunar chart. In 1827, however, his sight began to fail, and he was obliged to abandon his intention. But a successor had already appeared on the scene. *Johann Heinrich von Mädler* (1794-1874) was born in Berlin in 1794, and, after a severe struggle to earn a living, entered the University of Berlin in 1817. In 1824 he became acquainted with *Wilhelm Beer* (1797 - 1850), a wealthy banker, who had come to him for instruction in astronomy, and who erected in 1829 an observatory near his villa in Berlin, where pupil and tutor pursued their studies.

In 1830 Mädler, with Beer's assistance, commenced a great trigonometrical survey of the surface of the Moon. The observations of Beer and Mädler were made with no larger instrument than a $3\frac{3}{4}$-inch refractor. They ascertained the positions of 919 lunar spots, and measured the height of 1095 mountains. Their great chart of the Moon—which was afterwards followed by a smaller one—was issued in four

parts during 1834-36. "The amount of detail," wrote Proctor, "is remarkable, and the labour actually bestowed upon the work will appear incredible." The chart has neither been revised nor superseded, and it remains to this day one of the standard works on the subject.

The chart was succeeded in 1837 by a descriptive volume entitled 'Der Mond.' In this work Beer and Mädler did much for the progress of lunar astronomy. Their observations led to a change of opinion regarding our satellite's physical condition. Herschel, Schröter, Olbers, and other astronomers seem to have considered the Moon a living world. Mädler declared that it was a dead world. He believed it to be destitute of life of any kind, and the changes observed by Schröter and other observers were put down as illusions. 'Der Mond' was the end of Mädler's work in lunar astronomy, for, receiving an appointment at Dorpat, he went there in 1846, and retained his post until within a few years of his death, which took place at Hanover on March 14, 1874.

Mädler's successor in the field of lunar astronomy was *Johann Friedrich Julius Schmidt* (1825-1884), who was born at Eutin in Lübeck in 1825. At a very early age he gave indications of a taste for astronomy. Fortunately his

father possessed a small hand telescope, with which young Schmidt commenced his lunar studies. Appointed assistant at Bonn and Olmütz and director at Athens successively, he kept up his persistent study of the surface of the Moon for over forty years. In 1839, when fourteen years of age, he began the valuable series of observations which were destined to form the basis of his great chart of the surface of the Moon. Between 1853 and 1858, when employed at Olmütz, Schmidt made and calculated no fewer than 4000 micrometrical measures of the altitudes of lunar mountains. Before 1866 Schmidt had found no fewer than 278 "rills," and his discoveries were the means of augmenting the number of these curious objects to nearly a thousand.

In a word, it may be said that Schmidt drew out a lunar geography, and the result of his labours, together with those of Schröter and Mädler, is that in a sense we now know the features of the Moon better than those of the Earth. For instance, astronomers see the whole surface of the Moon spread before their eyes, while geographers can never have a similar view of the terrestrial features: we have never seen the poles of the Earth, while the lunar poles are well known to astronomers. For

twenty years after his appointment at Athens, Schmidt worked at fixing the positions of lunar objects, measuring the heights of mountains and the depths of craters. An idea of his enthusiasm in constructing his great chart may be gained from the fact that he made almost a thousand original sketches.

Mädler's dogmatic assertion that the Moon was entirely a dead world was generally believed until Schmidt made observations to the contrary. From 1837 to 1866 the popular opinion was that our satellite was an absolutely dead world. Consequently there was little progress in lunar astronomy during those thirty years. Although Mädler's view was much nearer the truth than the opinions of his predecessors, it was also too positive. His confident assertion, which was received without hesitation, was never questioned until Schmidt came upon the scene. To Schmidt the Moon was not entirely dead, and it was he who brought forward indisputable evidence as to the existence of changes on its surface. In October 1866 he announced that the crater Linné had lost all appearance of such, and that it had become entirely effaced. Lohrmann and Mädler had observed it under a totally different aspect, as also had Schmidt himself

from 1840 to 1843. There was great excitement in the astronomical world on Schmidt's announcement, and many astronomers denied the change, although Schmidt's observation was confirmed by Secchi and Webb. The evidence in favour of it preponderated, and very few observers now consider the Moon's surface to be absolutely changeless.

In 1865 Schmidt had begun to arrange his observations on the Moon into the form of a chart. At first he decided to have a chart of six feet diameter, divided, like that of Mädler, into four sections. But in April 1868, on making an estimate of the value of such a chart, he was dissatisfied, and determined to construct a map of the same size divided into twenty-five sections instead of four. He began the work in 1868, and after six years the great map was completed. After some delay the German Government undertook to issue the chart at their expense, and it was published in 1879, after fourteen years of preparation. It contained no fewer than 30,000 objects, and its completed diameter was six feet three inches—more than double the size of any previous map of the Moon. Indeed, it was probably the greatest contribution ever made to lunar astronomy. Schmidt lived only a few years

after the publication of his great chart. He died at Athens, in his fifty-ninth year, February 8, 1884.

Schmidt's announcement of the change in the appearance of Linné was followed in 1878 by a statement by *Hermann Joseph Klein* (born 1842) of Cologne, to the effect that a new crater had been formed to the north of the well-known lunar crater, Hyginus. The change in this case, however, is by no means so certain as in that of Linné. It will be observed that the majority of the students of the Moon were Germans. In England the study was not taken up until 1864, when a Lunar Committee of the British Association was appointed. Some good lunar work was done by the well-known astronomer, *Thomas William Webb* (1807-1885), while the study was popularised by *James Nasmyth* (1808-1890), the famous engineer, who published, in 1874, in conjunction with *James Carpenter* of Greenwich Observatory, a beautifully-illustrated volume entitled 'The Moon.' This was succeeded, in 1876, by the larger work of *Edmund Neison* (now Nevill), Government Astronomer of Natal. About this time several English astronomers, devoted to the study of the Moon, formed themselves into the Selenographical Society. After

a few years, however, the society came to an end, and the enthusiasts formed themselves into the lunar section of the British Astronomical Association, on the foundation of that society in 1890. Chief among those English selenographers was *Thomas Gwyn Elger* (1837-1897), whose observations of the Moon and drawings of the various craters were of the utmost value. Two years before his death, in 1895, Elger published his important work, 'The Moon,' along with an exhaustive chart of the visible face of our satellite.

Herschel and Schröter firmly believed in the existence of a lunar atmosphere, the latter believing that he had actually observed the Moon's atmospheric envelope. Early in the nineteenth century it was soon observed, however, that on the Moon passing over and occulting stars, these stars disappeared suddenly behind the Moon's limb, instead of gradually, as they should have done, had an atmosphere of any density existed. Accordingly astronomers gave up believing in a lunar atmosphere. On January 4, 1865, Huggins observed with his spectroscope the occultation of a small star in Pisces. There was not the slightest sign of absorption in a lunar atmosphere; the entire spectrum vanished at once.

Lunar photography was introduced as long ago as 1858 by *Lewis Morris Rutherfurd* (1816-1892), the well-known American astronomer; but for years very little was done in this matter, although Rutherfurd secured fairly good photographs. Rutherfurd, De la Rue, and the older astronomical photographers took photographs of the entire Moon, but this plan was abandoned in favour of what Miss Clerke calls "bit by bit photography." About 1890 this method was introduced, and has been followed with success by *Maurice Loewy* (born 1833), and his assistant, Pusiex, at the Paris Observatory; by *Ladislas Weinek* at Prague; by the astronomers of the Lick Observatory; and by *William Henry Pickering* (born 1858), the distinguished astronomer of Harvard, whose discoveries and investigations have created quite a new interest in lunar astronomy. These investigations were commenced in 1891 at Arequipa, on the slope of the Andes, in Peru. An occultation of Jupiter, witnessed by W. H. Pickering on October 12, 1892, gave support to the view that a very tenuous lunar atmosphere does exist. In 1900 he established, near Mandeville, Jamaica, a temporary astronomical station, where he obtained many excellent photographs. Totally he secured eighty plates. These appeared, as the first com-

plete photographic lunar atlas ever published, in his work 'The Moon' (1903), in which he sums up all his observations since 1891, and concludes that "the evidence in favour of the idea that volcanic activity upon the Moon has not yet ceased is pretty strong, if not fairly conclusive."

Pickering points out that the density of the lunar atmosphere is not greater than one ten-thousandth of that at the Earth's surface, and, under these circumstances, water cannot exist above freezing-point, which of course brings us to the subject of snow. He considers that snow is observed on the mountain peaks and near the poles of the Moon, and he believes his conclusion to be verified by observations on the well-known crater, Linné. He brings forward evidence of the probable existence on the Moon of organic life, pointing out that the difference between the conditions of the Earth and the Moon is not so great as that above and below the ocean on our own planet. He has collected evidence of the existence of something resembling vegetation on the Moon "coming up, flourishing, and dying, just as vegetation springs and withers on the Earth."

The first successful attempt to measure the heating power of moonlight was made in 1846 on Mount Vesuvius by *Melloni*, an Italian physicist,

whose results were confirmed four years later by *Zantedeschi*, another Italian. The most important work in this direction was accomplished by the present *Earl of Rosse* (born in 1840), who in the years 1869-72 believed himself to have measured the lunar heat; but these conclusions were not altogether confirmed by the observations of Dr *Otto Boeddicker* (Lord Rosse's astronomer), during the total lunar eclipse of October 4, 1884. Further investigations on this subject were afterwards made by *Samuel Pierpont Langley* (1834-1906), of Alleghany, and by his assistant, *Frank Very*.

The motion of the Moon and its perturbations were made the subject of deep study by the famous *Pierre Simon Laplace* (1749-1827), the contemporary of Herschel, and the worthy successor of Newton. He devoted much attention to the secular acceleration of the Moon's mean motion, a problem which had baffled the greatest mathematicians. After a profound discussion he found, in 1787, that the average distance of the Earth and Moon from the Sun had been slowly increasing for several centuries, the result being an increase in the Moon's velocity. In the third volume of the 'Mécanique Céleste' Laplace worked out the lunar theory in great detail, although he calculated no lunar tables. After

his death the subject was taken up by *Charles Theodore Damoiseau* (1768-1846), and the most important advance was made by *Giovanni Antonio Amadeo Plana* (1781-1864), the director of the Turin Observatory, who published in 1832 a very complete lunar theory. The work of Plana was followed by that of *Peter Andreas Hansen* (1795-1874), whose lunar tables were used for the Nautical Almanac, and whom Professor Simon Newcomb considers to be the greatest master of celestial mechanics since Laplace. The theory of the Moon's motion was worked out in detail by the famous astronomer *Charles Eugene Delaunay* (1816-1872), who from 1870 till 1872 occupied the post of director of the Paris Observatory. Delaunay was about to work out the lunar tables when, in 1872, he was accidentally drowned by the capsizing of a pleasure-boat at Cherbourg. The work accomplished in this direction by *Simon Newcomb* (born 1835) is of great importance, particularly in his correction of Hansen's tables. *John Couch Adams* (1819-1892), one of the discoverers of Neptune, while at work on the lunar theory, had occasion to correct Laplace's supposed solution of the acceleration of the lunar motion. On going over the calculation Adams found that several quantities, omitted by Laplace

as unimportant, showed that the Moon has a minute increase of speed for which the theory of gravitation will not account,—a conclusion opposed by Plana, Hansen, and Pontécoulant, but fully confirmed by Delaunay. Delaunay suggested in 1865 that the minute apparent increase was due to the retardation of the Earth's rotation by tidal friction. This brings us to the subject of celestial evolution, which is discussed in another chapter.

CHAPTER V.

THE INNER PLANETS.

MUCH progress has been made during the last hundred years in our knowledge of the planets. In fact, the study of Mercury only dates from the commencement of the nineteenth century. Our knowledge of the vicinity of the Sun is very limited, and Mercury is difficult of observation. So limited, in fact, is our knowledge of the Sun's surroundings, that it is not yet known for certain whether there is a planet, or planets, between Mercury and the Sun. Perturbations in the motion of the perihelion of Mercury's orbit led Le Verrier in 1859 to the belief that a planet of about the size of Mercury, or else a zone of asteroids, existed between Mercury and the Sun. It was, however, obvious that such a planet could only be seen when in transit across the Sun's disc, or during a total eclipse. Meanwhile a French doctor, Lescarbault, informed Le Verrier that he had seen a round object in

transit over the Sun's disc. Le Verrier, certain that this was the missing planet, named it "Vulcan," and calculated its orbit, assigning it a revolution period of twenty days. But it was never seen again. Transits of "Vulcan" were fixed for 1877 and 1882, but nothing was seen on these dates. During the total eclipse of July 29, 1878, two observers—*James Watson* (1838-1880), the well-known astronomer, and *Lewis Swift* (born 1820)—believed themselves to have discovered two separate planets, and ultimately claimed two planets each, which were never heard of again. During the total eclipse of 1883 an active watch for "suspicious objects" was kept, but with no result. At the eclipses of 1900 and 1901 respectively, photographs were exposed by the American astronomers, W. H. Pickering and *Charles Dillon Perrine* (born 1867), but on none of these plates could any trace of "Vulcan" be found. At the total eclipse of August 30, 1905, plates were again exposed, but no announcement has been made of an intra-Mercurial planet; and the prevalent opinion among astronomers is that no planet comparable with Mercury in size exists between that planet and the Sun.

The study of the physical appearance of Mercury was inaugurated by Schröter, who in

1800 noticed that the southern horn of the crescent presented a blunted appearance, which he attributed to the existence of a mountain eleven miles in height. From observations of this mountain he came to the conclusion that the planet rotated in 24 hours 4 minutes. This was afterwards reduced by *Friedrich Wilhelm Bessel* (1784-1846) to 24 hours 53 seconds.

After the time of Schröter there was no astronomer who paid much attention to either Mercury or Venus until the arrival on the scene of the most persistent planetary observer and one of the foremost astronomers of the nineteenth century. *Giovanni Virginio Schiaparelli* was born at Savigliano, in Piedmont, in 1835, and graduated at Turin in 1854. Called to Milan as assistant in the Brera Observatory in 1860, he became director in 1862, and there for thirty-eight years he studied astronomy in all its aspects, making a great name for himself in various branches of the science. In 1900 he retired from the post of director, and pursues his astronomical researches in his retirement.

In 1882 Schiaparelli took up the study of Mercury in the clear air of Milan. Instead of observing the planet through the evening haze, like Schröter and others, he examined it by day,

and was enabled to follow it hourly instead of looking at it for a short period when near the horizon. At length, after seven years' observation, he announced, on December 8, 1889, that Mercury performs only one rotation during its revolution round the Sun—in fact, that its day and year coincide. As a consequence, the planet keeps the same face towards the Sun, one side having everlasting day and the other perpetual night; but owing to the libratory movement of Mercury—the result of uniform motion on its axis and irregular motion in its orbit—the Sun rises and sets on a small zone of the planet's surface. Schiaparelli's observations indicated that Mercury is a much spotted globe, with a moderately dense atmosphere, and he was enabled to form a chart of its surface-markings.

Schiaparelli's conclusions remained until 1896 unconfirmed and yet not denied, although most astronomers were sceptical on the subject. In 1896 the subject was taken up by the American astronomer, *Percival Lowell* (born 1855), who, in the clear air of Arizona, confirmed Schiaparelli's conclusions, fixing 88 days as the period of rotation. He remarked, however, that no signs of an atmosphere or clouds were visible to him. The surface of Mercury, he says, is colourless,—"a geography in black and white." The deter-

mination of the rotation period by Schiaparelli and Lowell is now generally accepted, and is confirmed by the theory of tidal friction. It is only right to add that *William Frederick Denning* (born 1848) in 1881 suspected a rotation period of 25 hours, but this remains unconfirmed. In April 1871 the spectrum of Mercury was examined by *Hermann Carl Vogel* (born 1842) at Bothkamp. He suspected traces of an atmosphere similar to ours, but was not certain. Of more interest are the photometric observations of Zöllner in 1874. These observations indicated that the surface of Mercury is rugged and mountainous, and comparable with the Moon,—a conclusion supported by Lowell's observations in 1896.

Venus, the nearest planet to the Earth, has been attentively studied for three centuries, and still comparatively little is known regarding it. This is due to its remarkable brilliancy, combined with its proximity to the Sun. The great problem at the beginning of the nineteenth century was the rotation of the planet. In 1779 the subject was taken up by Schröter at Lilienthal. Nine years later, from a faint streak visible on the disc, he concluded that rotation was performed in 23 hours 28 minutes, and in 1811 this was reduced by seven minutes;

but as Herschel was unable to observe the markings seen by Schröter, many astronomers were inclined to be sceptical regarding the accuracy of the Lilienthal observer's results. Schröter also observed the southern horn of Venus when in the crescent form to be blunted, and he ascribed this to the existence of a great mountain, five or six times the elevation of Chimborazo; while he observed irregularities along the terminator, which he considered to be more strongly marked than those on the Moon. Schröter's opinion on this point, although rejected by Herschel, was confirmed by Mädler, Zenger, Ertborn, Denning, and by the Italian astronomer *Francesco Di Vico* (1805 - 1848), director of the Observatory of the Collegio Romano. In 1839 Di Vico attacked the problem of the rotation, and his results were confirmatory of those of Schröter. He estimated that the axis of Venus was inclined at an angle of 53° to the plane of its orbit. Meanwhile a series of important observations had been made on Venus by the Scottish astronomer and theologian, *Thomas Dick* (1772-1857), who suggested daylight observations on Venus to solve the problem of the rotation.

In 1877 the question was attacked by Schiaparelli, who commenced a series of ob-

servations on Venus at Milan in that year. The results of his studies were summed up in 1890 in five papers contributed to the Milan Academy. He came to the conclusion that the markings observed by Schröter, Di Vico, and others were not really permanent, and concentrated his attention on round white spots, which remained fixed in position. Instead of observing Venus in the evening, Schiaparelli followed it by day, watching it continuously on one occasion for eight hours. But the markings remained fixed. Schiaparelli accordingly concluded that the planet's rotation was performed in probably 225 days, equal to the time of revolution. One face is turned towards the Sun continually, while the other is perpetually in darkness.

The announcement was so startling that, as Miss Clerke says, "a clamour of contradiction was immediately raised, and a large amount of evidence on both sides of the question has since been collected." Perrotin at Nice, Tacchini at Rome, Cerulli at Teramo, Mascari at Catania and Mount Etna, and Lowell in Arizona, all in favourable climates, confirmed Schiaparelli's results, as also did a second series of observations by the Milan astronomer himself in 1895. On the other hand, Neisten, Trouvelot, *Camille*

Flammarion (born 1842), and others, under less favourable climatic conditions, arrived at a period of 24 hours. *Aristarch Bélopolsky* (born 1854), from spectroscopic observations at Pulkowa, by means of Doppler's principle, found a period of 12 hours. Lowell, by the same principle, found, in 1901-03, a period of 225 days, in agreement with Schiaparelli's results. This is the last word on the subject. Schiaparelli's rotation period, confirmed by the theory of tidal friction, is generally accepted.

That Venus has an atmosphere was one of the conclusions reached by Schröter in 1792; and in this at least he was correct, as the atmosphere of Venus, illuminated by the solar rays, has been seen extending round the entire disc of the planet. Spectroscopic observations by Tacchini, Ricco, and Young, during the transits of 1874 and 1882, indicated the existence of water-vapour in the planet's atmosphere. Very little has been discovered regarding the "geography" of Venus. White patches at the supposed "poles" of the planet were observed in 1813 by *Franz von Gruithuisen*, and in 1878 by the French astronomer *Trouvelot* (1827-1895). The secondary light of Venus, similar to the "old Moon in the new Moon's arms," was repeatedly observed since the time of Schröter

by Vogel, Lohse, Zenger, and others. Vogel attributed it to twilight, and Lamp, a German observer, to electrical processes analogous to our auroræ. In 1887 a Belgian astronomer, *Paul Stroobant*, submitted to a searching examination all the supposed observations of a satellite of Venus, and was enabled to explain nearly all the supposed satellites as small stars which happened to lie near the planet's path in the sky at the time of observation.

The study of our own planet can hardly be said to belong to the realm of astronomy. Nevertheless, it is through astronomical observation that the motion of the North Pole has been discovered. For many years it has been a problem whether there is a variation of latitude resulting from the motion of the pole. Euler had declared, from theoretical investigation, that, were there such a motion, the period must be 10 months. The question was revived in 1885 by the observations of *Seth Carlo Chandler* (born 1846) at Cambridge, Mass., with his newly-invented instrument, the "almucantar," which indicated an appreciable variation of latitude. This was confirmed by *Friedrich Küstner* (born 1856), now director of the Observatory at Bonn. The idea now occurred to Chandler to search through the older records

to discover if there was any trace of the variation of latitude, with the result that he brought out a period of 14 months instead of 10. This aroused much interest, and many prominent astronomers denied Chandler's results, which were announced in 1891. As a well-known astronomer has expressed it, "Euler's work had shown what period the motion must have, and any appearance of another period must be due to some error in the observations. Chandler replied to the effect that he did not care for Euler's mathematics: the observations plainly showed 14 months, and if Euler said 10, *he* must have made the mistake. I do not exaggerate the situation in the least; it was a deadlock: Chandler and observation against the whole weight of observation and theory." It was now shown by Newcomb that Euler had assumed the Earth to be an absolutely rigid body, while modern investigations show that it is not so. Chandler's discovery is now accepted, and proves that the North Pole is not fixed in position, but has a small periodic motion, though never twelve yards from its mean position. That the small resulting variation in the position of the stars has been noticed at all is a striking illustration of the accuracy of astronomical observation.

Of all the planets Mars has been most studied during the nineteenth century. Many illustrious astronomers have devoted years to the study of the red planet, with the result that more is known of the surface of Mars than of any other celestial body, with the exception of the Moon. After the time of Herschel, the leading students of Mars were Beer and Mädler, who carefully studied the planet from 1828 to 1839. They identified at each opposition the same dark spots, frequently obscured by mists, and they also made the most accurate determination of the rotation period, which they fixed at 24 hours 37 minutes 23 seconds. This estimate was confirmed in 1862 by *Friedrich Kaiser* (1808-1872) of Leyden, in 1869 by *Richard Anthony Proctor* (1837-1888), and in 1892 by *Henricius Gerardus van de Sande Bakhuyzen* (born 1838), director of the Leyden Observatory. In 1862 Lockyer identified the various markings seen by Beer and Mädler in 1830. The other great names in Martian study prior to 1877 are Angelo Secchi and *William Rutter Dawes* (1799-1868), who studied Mars from 1852 to 1865 and secured a very valuable series of drawings. These drawings were used by Proctor for the construction of the first reliable map of Mars, which was published in 1870 in his work, 'Other Worlds than Ours.'

Proctor gave names to the various Martian features, the reddish-ochre portions of the disc being named continents and the bluish-green portions seas; and Proctor's views on Mars found favour for many years. In 1877, however, Schiaparelli opened a new era in the study of Mars. In September of that year, during the very favourable opposition of the planet, Schiaparelli, while executing a trigonometrical survey of the disc, discovered that the continents were cut up by numerous long dark streaks, which he called *canali*. In 1879, to his surprise, he found that some of the canals had become double; and he confirmed this in 1881 and at subsequent oppositions. Meanwhile, as Schiaparelli was the only observer who had hitherto seen the canals, there was much scepticism as to their reality. In 1886, however, they were seen at the Nice Observatory by *Henri Perrotin* (1845-1904), who also observed their duplication. Since 1886 they have been observed by many astronomers, including Camille Flammarion in France, *William Frederick Denning* (born 1848) in England, *Vincenzo Cerulli* (born 1859) in Italy, Percival Lowell and W. H. Pickering in the United States. In 1892 W. H. Pickering successfully observed the canals, and discovered at the junctions of two or more canals round

black spots, to which he gave the name of "lakes," in keeping with the view that the dark regions of the planet were seas.

In 1894 Percival Lowell erected at Flagstaff, Arizona, an observatory for the specific purpose of observing Mars and its canals in good and steady air. He was assisted by W. H. Pickering and by *Andrew Ellicott Douglass* (born 1867). During a year's study Douglass measured the Martian atmosphere and discovered canals crossing the dark regions of the planet, finally disproving the idea of their aqueous character. Lowell recognised all Schiaparelli's canals, and discovered many more. He also attentively studied the south polar cap of Mars, which disappeared entirely on October 12, 1894. Lowell noticed, also, that as the cap melted the canals became darker, as if water was being conveyed down; and accordingly he adopted the view put forward by Schiaparelli, that the canals are waterways lined on either side by banks of vegetation. His observations were published in the end of 1895 in his work 'Mars.' He is of opinion that the reddish-ochre regions or "continents" are deserts, and the greenish areas marshy tracts of vegetation. The lakes are named by him "oases," and, as Miss Clerke observes, he "does not shrink from the full

implication of the term." He regards the canals as strips of vegetation fertilised by a small canal, much too small to be seen, an idea which originated with W. H. Pickering. The canals are believed by Lowell to be waterways down which the water from the melting polar cap is conveyed to the various oases. He considers, in fact, that the canals are constructed by intelligent beings with the express purpose of fertilising the oases, regarded by him as centres of population. He remarks that water is scarce on the planet, owing to its small size, and as a consequence the inhabitants are forced to utilise every drop. The canal system is the result.

Lowell's theory has not been cordially received —although it is now gradually gaining popularity,—and several other hypotheses have been propounded to explain the canals. Proctor, who died some years before Lowell's theory was given to the world, regarded them as rivers, but this view may now be looked upon as abandoned. It was suggested that the canals might be cracks in the surface of Mars or meteors ploughing tracks above it: and Professor *John Martin Schaeberle* (born 1853) of the Lick Observatory put forward the view that the canals were chains of mountains running over the light and dark regions. None of these theories, however, gained

popularity, and had to give way to a more popular theory, the "illusion" hypothesis, put forward by the Italian astronomer Cerulli, and supported by Newcomb and Maunder. On the basis of the illusion theory, Newcomb explains that the "canaliform" appearance "is not to be regarded as a pure illusion on the one hand or an exact representation of objects on the other. It grows out of the spontaneous action of the eye in shaping slight and irregular combinations of light and shade, too minute to be separately made out into regular forms." Experiments were made by Maunder in 1902, and the results pointed to the truth of the theory that the canals were really illusions. But the studies of Lowell at the oppositions of 1903 and 1905 have seriously weakened the hypothesis of Cerulli and Maunder, and strongly confirm the theory of the artificial origin of the canals. In 1903 Lowell was enabled, from a study of the development of the canals, to show the probability of their artificial nature, and his study of the double canals showed a distinct plan in their distribution. Finally, on May 11, 1905, several photographs of Mars were secured at the Lowell Observatory, on which the canals appeared, not as dots of light and shade, as on the illusion theory, but as straight dark lines. This goes far to prove the

reality of the canals,—in spite of the ridicule cast on them and their observers,—and consequently the truth of the theory of intelligent life in Mars.

Meanwhile the old-fashioned Martian observations have been continued in less favourable climates than Arizona and Italy by various astronomers, among them the famous Camille Flammarion, the American astronomers *James Edward Keeler* (1857-1900), *Edward Emerson Barnard* (born 1857), the English astronomer W. F. Denning, and others. These conscientious and painstaking observers have done much for Martian study in increasing the number of accurate delineations of the Martian surface.

The spectrum of Mars was first examined by Huggins in 1867. He found distinct traces of water-vapour, and this was confirmed by Vogel in 1872, and by Maunder some years later. In 1894, however, *William Wallace Campbell* (born 1862), the American astronomer, observing from the Lick Observatory, California, was unable to detect the slightest difference between the spectra of Mars and the Moon, indicating that Mars had no appreciable atmosphere; and from this he deduced that the Martian polar caps could not be composed of snow and ice, but of frozen carbonic acid gas. In 1895, however, Vogel confirmed his

previous observations, and reaffirmed the presence of water-vapour in the Martian atmosphere.

During the opposition of 1830, Mädler undertook an extensive search for a Martian satellite, but was unsuccessful. In 1862 the search was resumed by *Heinrich Louis D'Arrest* (1822-1875), the famous German observer, who was also unsuccessful. Accordingly the red planet was referred to by Tennyson as the "moonless Mars." In 1877 the search was taken up by *Asaph Hall*, the self-made American astronomer, born at Goshen, Connecticut, in 1829, and employed from 1862 to 1891 at the Naval Observatory, Washington. During the famous opposition of August 1877, favoured by the great 26-inch refractor, he succeeded in discovering two very small satellites of Mars, to which he gave the names of Phobos and Deimos. He determined the time of revolution of Phobos at 7 hours 39 minutes, and that of Deimos at 30 hours 17 minutes,—Phobos revolving round Mars more than three times for one rotation of the planet on its axis. These two satellites are very small, not more than thirty miles in diameter. After Hall's successful search, photographs were exposed at the Paris Observatory for other Martian satellites, but none was discovered. No further moons have been found belonging to the red

planet, nor is it likely that any further satellites of Mars are in existence.

The discovery of a zone of small planets in the space between Mars and Jupiter belongs completely to the nineteenth century, although the existence of a planet in the vacant space was suspected three centuries ago. In 1772 the subject was taken up by *Johann Elert Bode* (1747-1826), afterwards director of the Berlin Observatory, who investigated a curious numerical relationship, since known as Bode's Law, connecting the distances of the planets. If four is added to each of the numbers—0, 3, 6, 12, 24, 48, 96, and 192, the resulting series represents pretty accurately the distances of the planets from the Sun, thus—4 (Mercury), 7 (Venus), 10 (The Earth), 16 (Mars), 28, 52, (Jupiter), and 100 (Saturn). After the discovery of Uranus, in 1781, it was found that it filled up the number 196. Bode, however, saw that the number 28, between Mars and Jupiter, was vacant, and predicted the discovery of the planet. Aided by *Franz Xavier von Zach* (1754-1832), he called a congress of astronomers, which assembled in 1800 at Schröter's observatory at Lilienthal, when, for the purpose of searching for the missing planet, the zodiac was divided into twenty-four zones, each of which was given

to a separate astronomer. One of them was reserved for *Giuseppe Piazzi* (1746-1826), director of the Observatory of Palermo.

Born in 1746 at Ponte, in Lombardy, Giuseppe Piazzi, after entering the Theatine Order of monks, became in 1780 Professor of Mathematics at Palermo, where an observatory was erected in 1791; and at that observatory Piazzi worked till his death in 1826. In 1792 he commenced a great star-catalogue, and while making his nightly observations he discovered, on January 1, 1801—the first night of the nineteenth century, —what he took to be a tailless comet, but which proved to be a small planet revolving round the sun in the vacant space. The discovery was hailed by Bode and Von Zach with much enthusiasm, and Piazzi named the planet Ceres. The little planet was, however, soon lost in the rays of the sun before sufficient observations had been made; but the great mathematician, *Friedrich Gauss* (1777-1855), came to the rescue, and pointed out the spot where the planet was to be rediscovered. In that spot it was found on December 31, 1801, by Von Zach at Gotha, and on the following evening by *Heinrich Olbers* (1758-1840) at Bremen.

On March 28, 1802, while observing Ceres

from his house at Bremen, Olbers was struck by the presence of a strange object near the path of the planet. At first he supposed it to be a variable star at maximum brilliance, but a few hours showed him that it was in motion, and was therefore another planet. He named it Pallas, and propounded the theory that the two "Asteroids"—so named by Herschel—were fragments of a trans-Martian planet, which, through some accident, had been shattered to pieces in the remote past. Olbers urged the necessity of searching for more small planets. His advice was taken. In 1804 *Karl Ludwig Harding* (1765-1834), Schröter's assistant, discovered Juno, and Olbers himself detected Vesta, March 29, 1807.

After 1816 the search was relinquished, as no more planets were discovered. In 1830, however, a German amateur, *Karl Ludwig Hencke* (1793-1866), ex-postmaster of Driessen, commenced a search for new planets, which was rewarded, after fifteen years, by the discovery of Astræa, December 8, 1845. On July 1, 1847, he made another discovery, that of Hebe. A few weeks later, *John Russell Hind* (1823-1895), the English astronomer, discovered Iris. Since 1847 not a year has passed without one or more planets

being found, sometimes as many as twenty being discovered in a single year. Some astronomers have made the search for asteroids their chief business. The principal asteroid discoverers have been *Christian H. F. Peters* (1813-1890), Henri Perrotin, *Paul Henry* (1848-1905), *Prosper Henry* (1849-1903), James Watson, *Robert Luther* (1822-1900), *Johann Palisa* (born 1848), and *Max Wolf* (born 1863).

In 1891 a new impulse was given to asteroid study by the application of photography by Max Wolf to the discovery of the minor planets. It occurred to Wolf that the asteroid would be represented on the plate by a trail, caused by its motion during the time of exposure; and assisted by *Arnold Schwussmann* (born 1870), *Luigi Carnera* (born 1875), and others, Wolf has discovered over a hundred asteroids, and he has the whole field of asteroid hunting to himself. Few minor planets are now discovered by the older method. In 1901 Wolf invented his new instrument of research, the stereo-comparator, which, on the principle of the old-fashioned stereoscope, represents the planetary bodies as suspended in space far in front of the stars. In this way this ingenious astronomer has been enabled to discover asteroids at the

first glance: year by year fresh discoveries are announced from the Heidelberg Observatory, until more than five hundred asteroids are now known.

Waning interest in the ever-increasing family of asteroids was revived in 1898 by the discovery by *Karl Gustav Witt* (born 1866) of a small planet, to which he gave the name of Eros, which comes nearer to the Earth than Mars, and which is of great assistance to astronomers in the determination of the solar parallax. For some time prior to 1898 astronomers had considered it a waste of time to search for new asteroids; but this idea is not now so popular, in view of the benefit conferred on astronomy by the discovery of Eros.

Of the physical nature of the asteroids astronomers know nothing. Only the four largest have been measured. For many years it was supposed that Vesta, the brightest of the asteroids, was also the largest. The measures of Barnard with the great Lick refractor in 1895, however, showed that Ceres is the largest, with a diameter of 477 miles. Pallas comes next, with a diameter of 304 miles; while the diameters of Vesta and Juno are respectively 239 and 120 miles. Barnard saw no traces of atmo-

sphere round any of the asteroids. It should be stated that in 1872 Vogel thought he could detect an "air-line" in the spectrum of Vesta: he admitted that the observation required confirmation, but it has not been corroborated either by himself or any other observer.

CHAPTER VI.

THE OUTER PLANETS.

JUPITER, the greatest planet of the Solar System, has perhaps been more persistently studied by astronomers than any other. In the early nineteenth century the prevalent idea was that Jupiter was a world similar to the Earth, only much larger,—a view held by Herschel and other famous astronomers, and put forward by Brewster in 'More Worlds than One.' This view prevailed for many years, although Buffon in 1778, and Kant in 1785, had stated their belief in the idea that Jupiter was still in a state of great heat—in fact, that the great planet was a semi-sun. This idea, however, was long in being adopted by astronomers, and very little attention was paid to Nasmyth's expression of the same opinion in 1853. The older view still held the field—namely, that the belts of Jupiter represented trade-winds, and that a world similar to the terrestrial lay below the Jovian clouds. In 1860

George Philip Bond (1826-1865), director of the Harvard Observatory, found from experiments that Jupiter seemed to give out more light than it received, but he did not dare to suggest that Jupiter was self-luminous, considering that the inherent light might result from Jovian auroras.

In 1865 Zöllner showed that the rapid motions of the cloud-belts on both Jupiter and Saturn indicated a high internal temperature. At the distance of Jupiter sun-heat is only one twenty-seventh as great as on the Earth, and would be quite incapable of forming clouds many times denser than those on the Earth. In 1871 Zöllner drew attention to the equatorial acceleration of Jupiter, analogous to the same phenomenon on the Sun. In 1870 these opinions of Zöllner's were adopted and supported by Proctor in his 'Other Worlds than Ours.' In his subsequent volumes Proctor did much to popularise the idea, which is now accepted all over the astronomical world.

During the century many valuable observations on Jupiter were made by numerous observers, among them Airy, Mädler, Webb, Schmidt, and others. Much time was devoted to the accurate determination of the rotation period, which was fixed at 9 hours 55 minutes 36·56 seconds by Denning in observations from 1880 to 1903. No

really important discovery was made till 1878, when Niesten at Brussels discovered the "great red spot," a ruddy object 25,000 miles long by 7000 broad, attached to a white zone beneath the southern equatorial belt. This remarkable object has been observed ever since. In 1879 its colour was brick-red and very conspicuous, but it soon began to fade, and Riccó's observation at Palermo in 1883 was thought to be the last. After some months, however, it brightened up, and, notwithstanding changes of form and colour, it is still visible, a permanent feature of the Jovian disc. In 1879 a group of "faculæ," similar to those on the Sun, was observed at Moscow by *Theodor Alexandrovitch Brédikhine* (1831-1904), and at Potsdam by *Wilhelm Oswald Lohse* (born 1845). It was soon observed that the rotation period, as determined from the great red spot, was not constant, but continually increasing. A white spot in the vicinity completed its rotation in $5\frac{1}{2}$ minutes less, indicating the differences of rotation on Jupiter.

The great red spot has been observed since its discovery by Denning at Bristol and *George Hough* (born 1836) at Chicago. Twenty-eight years of observation have not solved the mystery of its nature. The researches made on it, in the words of Miss Clerke, "afforded grounds only

for negative conclusions as to its nature. It certainly did not represent the outpourings of a Jovian volcano; it was in no sense attached to the Jovian soil—if the phrase have any application to the planet; it was not a mere disclosure of a glowing mass elsewhere seethed over by rolling vapours."

In 1870 *Arthur Cowper Ranyard* (1845-1894), the well-known English astronomer, began to collect records of unusual phenomena on the Jovian disc to see if any period regulated their appearance. He came to the conclusion that, on the whole, there was harmony between the markings on Jupiter and the eleven-year period on the Sun. The theory of inherent light in Jupiter, however, has not been confirmed. The great planet was examined spectroscopically by Huggins from 1862 to 1864, and by Vogel from 1871 to 1873. The spectrum showed, in addition to the lines of reflected sunlight, some lines indicating aqueous vapour, and others which have not been identified with any terrestrial substance. A photographic study of the spectrum of Jupiter was made at the Lowell Observatory by Slipher in 1904, probably the most exhaustive investigation on the subject. The spectroscope has, however, given little support to the theory of inherent light, and "we are driven to con-

clude that native emissions from Jupiter's visible surface are local and fitful, not permanent and general."

Herschel's idea, that the rotations of the four satellites of Jupiter were coincident with their revolutions, has on the whole been confirmed by recent researches, although in the case of the two near satellites (Io and Europa) W. H. Pickering's observations in 1893 indicated shorter rotation periods. There is much to learn regarding the geography of the satellites, although in 1891 Schaeberle and Campbell at the Lick Observatory observed belts on the surface of Ganymede, the third satellite analogous to those on Jupiter. Surface-markings on the satellites have also been seen by Barnard at the Lick Observatory, and by Douglass at Flagstaff.

Since the time of Galileo no addition had been made to the system of satellites revolving round Jupiter. Profound surprise was created, therefore, by the announcement of the discovery of a fifth satellite by Barnard at the Lick Observatory, on September 9, 1892. The satellite, one of the faintest of telescopic objects, was discovered with the great 36-inch telescope, and its existence was soon confirmed by *Andrew Anslie Common* (1841-1903), with his great 5-foot reflector at Ealing, near London. The new

satellite was found by Barnard to revolve round Jupiter in 11 hours 57 minutes at a mean distance of 112,000 miles.

Although the existence of other satellites of Jupiter was predicted by Sir *Robert Stawell Ball* (born 1840) soon after the discovery of the fifth, much surprise was created by the announcement, in January 1905, that a sixth satellite had been discovered by Perrine, who, in the following month, announced the discovery of a seventh. These discoveries were made by photography, the objects being very faint. The periods of revolution were found to be 242 days and 200 days for the sixth and seventh satellites respectively, the mean distances being 6,968,000 and 6,136,000 miles. It is possible that they may belong to a zone of asteroidal satellites. In fact, the fifth moon may belong to a similar zone, so that Jupiter may have two asteroidal zones; but this is anticipating future discovery.

A particular charm has always attached itself to the study of Saturn, the ringed planet. The magnificent system of rings has for two and a half centuries been the object of wonder and admiration in the Solar System, and accordingly they have been exhaustively studied by many eminent observers. While observing the two bright rings of Saturn on June 10, 1838, Galle

noticed what Miss Clerke calls "a veil-like extension of the lucid ring across half the dark space separating it from the planet." No attention, however, was paid to Galle's observation. On November 15, 1850, *William Cranch Bond* (1789-1859), of the Harvard Observatory in Massachusetts, discovered the same phenomenon under its true form—that of a dusky ring interior to the more brilliant one. A fortnight later, before the news of Bond's observation, Dawes made the same discovery independently at Wateringbury in England. This ring is known as the dusky or "crape" ring.

The discovery of the dusky ring brought to the front the problem of the composition of the ring-system. Laplace and Herschel considered the rings to be solid, but this was denied in 1848 by *Edouard Roche* (1820-1880), who believed them to consist of small particles, and in 1851 by G. P. Bond, who asserted that the variations in the appearance of the system were sufficient to negative the idea of their solidity; but he suggested that the rings were fluid. In 1857 the question was taken up by the Scottish physicist, *James Clerk-Maxwell* (1831-1879), who proved by mathematical calculation that the rings could be neither solid nor fluid, but were due to an aggregation of small particles,

so closely crowded together as to present the appearance of a continuous whole. Clerk-Maxwell's explanation — which had been suggested by the younger Cassini in 1715, and by Thomas Wright in 1750 — was at once adopted, and has since been proved by observation. In 1888 *Hugo Seeliger* (born 1849), director of the Munich Observatory, showed from photometric observations the correctness of the satellite-theory; while Barnard in 1889 witnessed an eclipse of the satellite Japetus by the dusky ring. The satellite did not disappear, but was seen with perfect distinctness. The final demonstration of the meteoric nature of the rings was made by Keeler at the Alleghany Observatory in 1895, with the aid of the spectroscope. By means of Doppler's principle, he found that the inner edge of the ring revolved in a much shorter time than the outer, proving conclusively that they could not be solid. This was confirmed by the observations of Campbell at Mount Hamilton, *Henri Deslandres* at Meudon, and Bélopolsky at Pulkowa.

In 1851 a startling theory regarding Saturn's rings was put forward by the famous *Otto Wilhelm von Struve* (1819-1905). Comparing his measurements on the rings made at Pulkowa in 1850 and 1851 with those of other astronomers

for the past two hundred years, he reached the conclusion that the inner diameter of the ring was decreasing at the rate of sixty miles a-year, and that the bodies composing the rings were being drawn closer to the planet. Accordingly, Struve calculated that only three centuries would be required to bring about the precipitation of the ring-system on to the globe of Saturn. In 1881 and 1882 Struve, expecting a further decrease, made another series of measures, but these did not confirm his theory, which was accordingly abandoned.

The study of the globe of Saturn has made less progress than that of the rings. The surface of the planet had been known since before the time of Herschel to be covered with belts, but as spots seldom appear on Saturn, only one determination of the rotation period had been made, that by Herschel. Much interest was aroused, therefore, by the discovery, by Hall, at Washington, on December 7, 1876, of a bright equatorial spot. Hall studied this spot during sixty rotations of the planet, determining the period as 10 hours 14 minutes 24 seconds. This was confirmed by Denning in 1891, and by *Stanley Williams*, an English observer, in the same year. On June 16, 1903, Barnard, at the Yerkes Observatory, discovered a bright spot, from

which he deduced a rotation period of 10 hours 39 minutes,—a period considerably longer than that found by Hall. In the same year various spots on Saturn were observed by Denning, who found a period of 10 hours 37 minutes 56·4 seconds, and at Barcelona by *José Comas Sola*, now director of the Observatory there, who may be considered Spain's leading astronomer. The result of these observations has been to show that the spots on Saturn have probably a proper motion of their own, apart from the rotation of the planet. As to the spectrum of Saturn, little has been learned. It closely resembles that of Jupiter. In 1867 Janssen, observing from the summit of Mount Etna, found traces of aqueous vapour in the planet's atmosphere.

In the chapters on Herschel we have seen that he discovered the sixth and seventh satellites of Saturn. The next discovery was made on September 19, 1848, by W. C. Bond, at Harvard, Massachusetts, and independently by *William Lassell* (1799-1880), at Starfield, near Liverpool. The new satellite received the name of Hyperion, and was found to be situated at a distance of about 946,000 miles from Saturn. Its small size led Sir John Herschel to the idea that it might be an asteroidal satellite.

Fifty years elapsed before another satellite of Saturn was discovered. In 1888 W. H. Pickering commenced a photographic search for new satellites of the planet. At last, on developing some photographs of Saturn, taken on August 16, 17, and 18, 1898, he found traces of a new satellite which he named "Phœbe." But, as the satellite was not seen or photographed again for some years, many astronomers were sceptical as to its existence. However, photographs taken in 1900, 1901, and 1902 revealed the satellite, which was again photographed in 1904, and seen visually by Barnard in the same year with the 40-inch Yerkes telescope. At that time the discoverer brought out the amazing fact that the motion of the satellite is retrograde—a fact which he attempts to explain by a new theory of the former rotation of Saturn. He likewise demonstrated that its distance from Saturn varied from 6,120,000 to 9,740,000 miles. Early in 1905 Pickering announced the discovery of a tenth satellite of Saturn, which received the name of Themis, with a period and mean distance nearly similar to Hyperion, so that Sir John Herschel's idea of Hyperion being an asteroidal satellite is being confirmed after a lapse of half a century.

If little is known of the globe of Saturn, still less is known regarding Uranus. Dusky bands

resembling those of Jupiter were observed by Young at Princeton in 1883. In the following year Paul and Prosper Henry discerned at Paris two grey parallel lines on the disc of the planet. This was confirmed by the observations of Perrotin at Nice, which also indicated rotation in a period of ten hours. In 1890 Perrotin again took up the study and re-observed the dark bands. On the other hand, no definite results regarding the planet were obtained by the Lick observers in 1889 and 1890. Measurements of the planet by Young, Schiaparelli, Perrotin, and others indicate a considerable polar compression. The spectrum of the planet has been studied by Secchi, Huggins, Vogel, Keeler, Slipher, and others. The spectrum shows six bands of original absorption, a line of hydrogen, which, says Miss Clerke, "implies accordingly the presence of free hydrogen in the Uranian atmosphere, where a temperature must thus prevail sufficiently high to reduce water to its constituent elements." From a photographic study of the spectrum at the Lowell Observatory in 1904, Slipher observed a line corresponding to that of helium, indicating the presence of that element in the planet's atmosphere.

Herschel left our knowledge of the Uranian satellites in a very uncertain state. The two

outer satellites, Titania and Oberon, were rediscovered in 1828 by his son, but the other four, which he was believed to have discovered, were never seen again. In 1847 two inner satellites, Ariel and Umbriel, were discovered by Lassell and Otto Struve respectively, their existence being finally confirmed by Lassell's observations in 1851.

After the discovery of Uranus by Herschel, mathematical astronomers determined its orbit and calculated its position in the future. *Alexis Bouvard*, the calculating partner of Laplace, published tables of the planet's motions, founded on observations made by various astronomers who had considered it a star before its discovery by Herschel; but as the planet was not in the exact position which Bouvard predicted, he rejected the earlier observations altogether. For a few years the planet conformed to the Frenchman's predictions, but shortly afterwards it was again observed to move in an irregular manner, and the discrepancy between observation and the calculations of mathematicians became intolerable. Did the law of gravitation not hold good for the frontiers of the Solar System? Gradually astronomers arrived at the conclusion that Uranus was being attracted off its course by the influence of an unseen body, an exterior

planet. Bouvard himself was one of the first to make the suggestion, but died before the planet was discovered. An English amateur, the Rev. *T. J. Hussey*, resolved to make, in 1834, a determination of the place of the unseen body, but found his powers inadequate; and in 1840 Bessel laid his plans for an investigation of the problem, but failing health prevented him carrying out his design.

In 1841 a student at the University of Cambridge resolved to grapple with the problem. John Couch Adams, born at Lidcot in Cornwall in 1819, entered in 1839 the University of Cambridge, where he graduated in 1843. From 1858 Professor of Astronomy at Cambridge, and from 1861 director of the Observatory, he died on January 21, 1892, after a life spent in devotion to mathematical astronomy. In 1843, on taking his degree, he commenced the investigation of the orbit of Uranus. For two years he worked at the difficult question, and by September 1845 came to the conclusion that a planet revolving at a certain distance beyond Uranus would produce the observed irregularities. He handed to *James Challis* (1803-1882), the director of the Cambridge Observatory, a paper containing the elements of what was named by Adams "the new planet." On

October 21 of the same year he visited Greenwich Observatory, and left a paper containing the elements of the planet, and approximately fixing its position in the heavens. But the Astronomer-Royal of England, Sir *George Biddell Airy* (1801-1892), had little faith in the calculations of the young mathematician. He always considered the correctness of a distant mathematical result to be a subject rather of moral than of mathematical evidence: in fact, regarding Uranus, the Astronomer-Royal almost called in question the correctness of the law of gravitation. Besides, the novelty of the investigations aroused scepticism, and the fact that Adams was a young man, and inexperienced, went against Airy's acceptance of the theory. However, he wrote to Adams questioning him on the soundness of his idea. Adams thought the matter trivial, and did not reply. Airy, therefore, took no interest in the investigations, and no steps were taken to search for the unseen planet. Meanwhile the Rev. W. R. Dawes happened to see Adams' papers lying at Greenwich, and wrote to his friend, the well-known astronomer Lassell, who was in possession of a very fine reflector, erected at his residence near Liverpool, asking him to search for the planet. But Lassell was suffering from a sprained ankle,

and Dawes' letter was accidentally destroyed by a housemaid. So Adams' theory remained in obscurity.

The question now came under the notice of *François Jean Dominique Arago* (1786-1853), the director of the Paris Observatory. He recognised in a young friend of his a rising genius, who was competent to solve the problem. Urban Jean Joseph Le Verrier, born at Saint Lo, in Normandy, in 1811, became in 1837 astronomical teacher in the École Polytechnique, and in 1853 director of the Paris Observatory. In consequence of differences with his staff he was obliged, in 1870, to resign from this position, but two years later was restored to the post, which he held till his death on September 23, 1877.

In 1845, ignorant of the fact that Adams had already solved the problem, Le Verrier began his investigations of the irregular motions of Uranus. In a memoir communicated to the Academy of Sciences in November of that year, he demonstrated that no known causes could produce these disturbances. In a second memoir, dated June 1, 1846, he announced that an exterior planet alone could produce these effects. But Le Verrier had now before him the difficult task of assigning an approximate position to the unseen body, so that it might be telescopically

discovered. After much calculation Le Verrier, in his third memoir (August 31, 1846), assigned to the planet a position in the constellation Aquarius.

Meanwhile one of Le Verrier's papers happened to reach Airy. Seeing its resemblance to Adams' papers, which had been lying on his desk for months, his scepticism vanished, and he suggested to Challis that the planet should be searched for with the Cambridge equatorial. In July 1846 the search was commenced. The planet was actually observed on August 4 and 12, but, owing to the absence of star maps, it was not recognised. "After four days of observing," he wrote to Airy, "the planet was in my grasp if I had only examined or mapped the observations."

Le Verrier wrote to Encke, the illustrious director of the Berlin Observatory, desiring him to make a telescopic search for a planetary object situated in the constellation Aquarius, as bright as a star of the eighth magnitude and possessed of a visible disc. "Look where I tell you," wrote the French astronomer, "and you will see an object such as I describe." Encke ordered his two assistants, Galle and D'Arrest, to make a search on the night of September 23, 1846. In a few hours Galle observed an object not

marked in the star-maps of the Berlin Observatory, which had been recently published. The following night sufficed to show that the object was in motion, and was therefore a new planet. On September 29 Challis found the planet at Cambridge, but he was too late, as the priority of the discovery was now lost to Adams. The planet received the name of "Neptune."

For some time, indeed, it appeared as if the French astronomer alone was to receive the honour of the discovery. But on October 3, 1846, a letter from Sir John Herschel appeared in the 'Athenæum' in which he referred to the discovery made by Adams. The French scientists were extremely jealous. Indeed, Arago actually declared that, when Neptune was under discussion, the entire honour should go to Le Verrier, and the name of Adams should not even be mentioned,—Arago's line of reasoning being that it was not the man who first made a discovery who should receive the credit, but he who first made it public. However, the credit of the discovery is now given equally to Adams and Le Verrier, both of whom are regarded as among the greatest of astronomers.

Only a fortnight after the discovery of Neptune, the astronomer Lassell observed a satellite to the distant planet on October 10, 1846. This

discovery was confirmed in July 1847 by the discoverer himself, and shortly afterwards by Bond and Otto Struve. Regarding the globe of Neptune, we know practically nothing. No markings of any kind have been observed on its surface. However, in 1883 and 1884, *Maxwell Hall*, an astronomer in Jamaica, noticed certain variations of brilliance which suggested a rotation-period of eight hours, but this was not confirmed by any other astronomer. The spectrum of Neptune has been investigated by various observers, who have found it to be similar to that of Uranus.

The existence of a trans-Neptunian planet has been suspected by many astronomers. In November 1879 the first idea of its existence was thrown out by Flammarion in his 'Popular Astronomy.' Flammarion noticed that all the periodical comets in the Solar System have their aphelion near the orbit of a planet. Thus Jupiter owns about eighteen comets; Saturn owns one, and probably two; Uranus two or three; and Neptune six. The third comet of 1862, however, along with the August meteors, goes farther out than the orbit of Neptune. Accordingly, Flammarion suggested the existence of a great planet, assigning it a period of 330 years and a distance of 4000 millions of miles.

Two independent investigators, *David Peck Todd* (born 1855) in America and *George Forbes* in Scotland, have since undertaken to find the planet. Todd, utilising the "residual perturbations" of Uranus, assigned a period of 375 years for his planet. Forbes, on the other hand, working from the comet theory, stated his belief in the existence of two planets with periods of 1000 and 5000 years respectively. In October 1901 he computed the position of the new planet on the celestial sphere, fixing its position in the constellation Libra, and computing its size to be greater than Jupiter. A search was made by means of photography, in 1902, but without success. Nevertheless, astronomers are pretty confident of the existence of one or more trans-Neptunian planets. Lowell is very definite on this subject when he says in regard to meteor groups, "The Perseids and the Lyrids go out to meet the unknown planet, which circles at a distance of about forty-five astronomical units from the Sun. It may seem strange to speak thus confidently of what no mortal eye has seen, but the finger of the sign-board of phenomena points so clearly as to justify the definite article. The eye of analysis has already suspected the invisible."

CHAPTER VII.

COMETS.

At the time of Herschel the ancient superstitions in regard to comets had to a great extent vanished, thanks mainly to the return of Halley's comet in 1758. Yet, although comets had ceased to be objects of terror, no explanation or rational theory of their nature was put forward until the appearance of the great comet of 1811. This comet was visible from March 26, 1811, to August 17, 1812, a period of 510 days. It was one of the most magnificent comets ever seen, its tail being 100 millions of miles in length and its head 127,000 miles in diameter. This wonderful phenomenon was the subject of much investigation, particularly by Olbers, the great German astronomer.

Heinrich Wilhelm Matthias Olbers was born at Arbergen, a village near Bremen, October 11, 1758. His father was a clergyman who, in

addition to considerable mathematical powers, was an enthusiastic lover of astronomy. At the age of thirteen young Olbers became deeply interested in that science. While taking an evening walk in the month of August, he observed the Pleiades, and determined to find out to which constellation they belonged. He therefore bought some books on astronomy, along with a few charts of the sky, and he began to study the science with much enthusiasm. He read every book he could lay his hands on, and a few months sufficed to make him acquainted with all the constellations.

In 1777, when in his nineteenth year, Olbers entered the University of Göttingen to study medicine, and at the same time he learned much regarding mathematics and astronomy from the mathematician Kaestner. When twenty-one years of age he observed the stars at Göttingen, and devised a method of calculating the orbits of comets, the idea coming to him while he was attending at the bedside of a fellow-student who had taken ill. "Although not made public until 1797," writes Miss Clerke, "'Olbers' method' was then universally adopted, and is still regarded as the most expeditious and convenient in cases where absolute rigour is not required. By its intro-

duction, not only many a toilsome and thankless hour was spared, but workers were multiplied and encouraged in the pursuit of labours more useful than attractive."

Towards the end of 1781 he returned to Bremen, settled as a medical doctor, and continued in practice for about forty-one years. But although he had adopted perhaps the most toilsome profession, his love of science prevailed, and night after night he explored the heavens with untiring zeal. He never slept more than four hours, and the upper part of his house in the Sandgasse, in Bremen, was fitted up with astronomical instruments. The largest telescope which he possessed was a refractor $3\frac{3}{4}$ inches in aperture. He remained in active practice till 1823, when he retired, and was enabled to devote more attention to his beloved science. He died on March 2, 1840, at the advanced age of eighty-one.

Miss Clerke says of Olbers, "Night after night, during half a century and upwards, he discovered, calculated, or observed the cometary visitants of northern skies." He was the discoverer of the comet of 1815, known as Olbers' comet. It moves round the Sun in a period of over seventy years, and returned to perihelion in 1887, forty-seven years after the death of its

discoverer. The great comet of 1811 was the subject of a memoir which Olbers published the following year, and in which he originated the "electrical repulsion" theory of comets' tails. Even after the fulfilment of Halley's great prediction, comets were still looked upon with profound awe, and the popular fear regarding them was still prevalent. Olbers, however, showed that the tails of comets resulted from purely natural causes. He regarded the Sun as possessed of a repulsive as well as an attractive force, and considered the tails to be vapours repelled from the nucleus of the comet by the Sun. He calculated that in the comet of 1811 the particles of matter expelled from the head reached the tail in eleven minutes, with a velocity comparable to that of light. The theory of electrical repulsion, since elaborated by other observers, is now generally accepted among astronomers. No other hypothesis represents in such a complete manner the formation and growth of the luminous appendages of the celestial bodies so picturesquely called "pale-winged messengers" as that put forward by the physician of Bremen.

Some years after Olbers' famous theory was given to the world, a great advance was made

in cometary astronomy by another great German astronomer, his friend and pupil Encke. The son of a Hamburg clergyman, Johann Franz Encke was born in that city in 1791, and died in 1865 at Spandau. After taking part in the war against Napoleon, he was in 1822 appointed director of the Gotha Observatory, being called to Berlin in 1825. In early life he was the pupil of Olbers and Gauss, and his investigations and discoveries formed an epoch in astronomy. His most famous discovery related to the little comet which bears his name. The comet was discovered by *J. L. Pons* (1761-1831) at Marseilles, although it had previously been seen by Méchain and Caroline Herschel. In 1819 Encke computed the orbit of the comet, and boldly announced that it would reappear in 1822, its period being about $3\frac{1}{4}$ years, or 1208 days. In 1822 the comet, true to Encke's prediction, returned to perihelion, and was observed at Paramatta in Australia, the perihelion passage taking place within three hours of the time predicted by Encke. As Miss Clerke remarks, "The importance of this event will be better understood when it is remembered that it was only the second instance of the recognised return of a comet; and that it, moreover, established the existence of a new

class of celestial bodies, distinguished as comets of short period."

In 1825 the comet was again observed by Valz, passing perihelion on September 16, and in 1828 it was seen by Struve. Encke now made a very remarkable discovery. Determining its period with great accuracy, in 1832 he found that his comet returned to perihelion two and a half hours before the predicted time. As this repeatedly happened, Encke put forward the theory that the acceleration was due to the existence of a resisting medium in the neighbourhood of the Sun, too rarefied to retard the planetary motions, but quite dense enough to make the comet's path smaller, and to eventually precipitate it on the Sun. The theory was widely accepted, but after 1868 the acceleration began to decrease, diminishing by one-half; besides, no other comet is thus accelerated, and the hypothesis has accordingly been abandoned.

The second comet recognised as periodic was that discovered on February 27, 1826, by an Austrian officer, *Wilhelm von Biela* (1782-1856), and ten days later by the French observer, *Gambart* (1800-1836), both of whom, in computing its orbit, noticed a remarkable similarity to the orbits of comets which appeared in 1772 and 1805. Accordingly, they concluded it to

be periodic, with a period of between six and seven years. The comet returned in 1832. In 1828 Olbers had published certain calculations showing that portions of the comet would sweep over the part of the Earth's orbit a month later than the Earth itself. This gave rise to a panic that the comet would destroy the Earth, which did not subside till it was announced by Arago that the Earth and the comet would at no time approach to within fifty million miles of each other. The comet returned again in the end of 1845. It was kept well in view by astronomers in Europe and America. On December 19, 1846, Hind noticed that the comet was pear-shaped, and ten days later it had divided in two. The two comets returned again in 1852 and were well observed; but they were never seen again, at least as comets. Their subsequent history belongs to meteoric astronomy.

A comet discovered by Faye at Paris in 1843 was found to have a period of seven and a half years. It has returned regularly since its discovery, true to astronomical prediction. Its motion was particularly investigated for traces of a resisting medium, by *Didrik Magnus Axel Möller* (1830-1896), director of the Lund Observatory, who reached a negative conclusion.

In 1835 Halley's comet returned to perihelion, and was attentively studied by the most famous astronomers of the age. It was particularly studied by Sir John Herschel and by Bessel, who assisted in developing Olbers' theory of electrical repulsion. But the most brilliant comet of the century was that which suddenly appeared on February 28, 1843, in the vicinity of the Sun. This great comet, whose centre approached the Sun within 78,000 miles, rushed past its perihelion at the speed of 366 miles a second. The comet's tail reached the length of 200 millions of miles. The comet of 1843 was however outshone, not in brilliance but as a celestial spectacle, by the great comet discovered on June 2, 1858, by *Giovanni Battista Donati* (1826-1873) at Florence, and since known by his name. It became visible to the naked eye on August 19, and was telescopically observed until March 4, 1859. There was abundance of time, therefore, to study the comet, which was exhaustively observed by G. P. Bond at Harvard. His observations convinced him that the light from Donati's comet was merely reflected sunshine, and this was generally accepted. Another great comet appeared in 1861. Like that of 1843, its appearance was sudden, being observed after sunset on June 30, 1861, when, says Miss

Clerke, "a golden yellow planetary disc, wrapt in dense nebulosity, shone out while the June twilight in these latitudes was still in its first strength." On the same evening the Earth and the Moon passed through the tail of the great comet. The vast majority of people never knew that such a phenomenon had taken place, and even the astronomers only noticed a singular phosphorescence in the sky — a proof of the extreme tenuity of comets.

The first application of the spectroscope to the light of comets was made by Donati in 1864. The spectrum was found to consist of three bright bands, but Donati was unable to identify them. However, his observation gave the death-blow to the theory that comets shone by reflected light alone, for it implied the existence of glowing gas in them. On the appearance in 1868 of the periodic comet discovered by *Friedrich August Theodor Winnecke* (1835-1897), the spectrum was examined by Huggins, who identified the bright bands with the spectrum of hydrocarbon. This was confirmed in regard to Coggia's comet of 1874 by Huggins himself, and also Brédikhine and Vogel. The hydrocarbon spectrum is characteristic of comets, and has been recognised in all those spectroscopically studied.

The time had now come for a more complete

theory of comets than that of Olbers. The theory of electrical repulsion was developed in 1871 by Zöllner, whose principle of investigation is thus described by Miss Clerke: "The efficacy of solar electrical repulsion relatively to solar attraction grows as the size of the particle diminishes." If the particle is small enough, it will obey the repulsive, and not the attractive, power of the Sun. Zöllner considered that the smallest particles of comets obeyed the repulsive power, and thus formed the tails of comets. The development of a complete cometary theory is due, however, to the genius of a Russian astronomer. Theodor Alexandrovitch Brédikhine, born in 1831 at Nicolaieff, was employed at Moscow Observatory from 1857 to 1890, when he was promoted to the position of director at Pulkowa. He resigned in 1895, and spent his last years in St Petersburg, where he died on May 14, 1904. From the beginning of his astronomical career he was devoted to the study of comets and their tails, but it was the appearance of Coggia's comet in 1874 which marked the commencement of his most important observations. In that year, on making certain calculations regarding the hypothetical repulsive force exerted by the Sun on various comets, he reached the conclusion that the values repre-

senting the intensity of the repulsion fell into three classes. This was the first hint of a classification of cometary tails. Meanwhile he carefully studied the tails of comets both from direct observation and from drawings.

In 1877 he wrote: "I suspect that comets are divisible into groups, for each of which the repulsive force is perhaps the same." Subsequent investigations led Brédikhine to divide the tails of comets into three types. The first type consists of long, straight tails, pointed directly away from the Sun, represented by the tails of the great comets of 1811, 1843, and 1861. In the second type, represented by Donati's and Coggia's comets, the tails, although pointed away from the Sun, appear considerably curved. In the third type the tails are, to quote Miss Clerke, "short, strongly-bent, brushlike emanations, and in bright comets seem to be only found in combination with tails of the higher classes."

In 1879 Brédikhine fully developed his cometary theory. Assuming the reality of the repulsive force, he concluded that to produce tails of the first type, the repulsion requires to be twelve times greater than the solar attraction; the production of tails of the second type necessitates a repulsive force about equal to gravity; while the force producing third-type

tails has only one-fourth the power of gravitation. It was concluded that the tails are formed by particles of matter repelled from the comet by the repulsive force of the Sun, and in tails of the first type the velocity with which these particles leave the body of the comet is four or five miles a second. Brédikhine reached the conclusion that the Sun's repulsive force is invariable, and that the different types of tails are formed by the same force acting on different elements. The numbers 12, 1, and $\frac{1}{4}$, are inversely proportional to the atomic weights of hydrogen, hydrocarbon gas, and iron vapour. Here, then, was the key to the mystery. Brédikhine pointed out that in all probability the first-type tails are formed of hydrogen, the second of hydrocarbon, and the third of iron, with a mixture of sodium and other elements.

Within a few years of the publication of Brédikhine's theory, five bright comets made their appearance, and there was abundant chance of testing the theory spectroscopically. In 1882 Well's comet was particularly studied at Greenwich by Maunder, who discerned a sodium-line in its spectrum. The magnificent comet which appeared in 1882 was spectroscopically studied at Dunecht in Aberdeenshire by *Ralph Copeland* (1837-1905), Astronomer-Royal of Scotland, who

identified in its spectrum the prominent iron-lines as well as the sodium-line. These observations were certainly confirmatory of Brédikhine's theory. It should also be stated, however, that several comets have shown, in addition to the hydrocarbon spectrum, that of reflected sunlight, which proves that the light we receive from comets is of a compound nature.

The comet which appeared in 1880 was announced by *Benjamin Apthorp Gould* (1824-1896) to be a return of the great comet of 1843. Calculations by Gould, Copeland, and Hind revealed a close similarity between the elements of the two orbits. Eventually it had to be admitted that the comets were separate bodies travelling in the same orbit. Then, two years later, the great September comet of 1882 was found to revolve in the same orbit as those of 1668, 1843, and 1880. Four years later, another comet, discovered in 1887, was found to move in the same path.

Closely allied to this subject is the existence of "comet families," demonstrated by Hoek of Utrecht in 1865, and mentioned in our chapter on the Outer Planets. These comets are found to be dependent on the planets, Jupiter, Saturn, Uranus, and Neptune, each possessing a comet-group. Various theories have been advanced to

account for the existence of these groups. One of these theories is that the comets have been captured by the various planets, who have forced them into their present orbits. A mathematical study by *Jean Pierre Octave Callandrean* (1852-1904) shows that the large number of comets possessed by the various planets may be explained by the disintegration of large comets into small ones. The capture theory, it must be remembered, is purely hypothetical, and must not be regarded as anything but a theory. All that we really know is the existence of comet-families, and of comets moving in the same orbits.

The first photograph of a comet was that of Donati's, taken in 1858 by Bond. In 1881 Tebbutt's comet was photographed in England by Huggins, and in America by *Henry Draper* (1837-1882), while in 1882 Gill secured excellent photographs of the great September comet. The first photographic discovery of a comet was made by Barnard in 1892. Since then photography has been much used in cometary astronomy. No bright comets have appeared since 1882,—if we except the comet of 1901, only seen in the southern hemisphere, — although several have been just visible to the naked eye, among them Swift's comet of 1892 and Perrine's in the autumn of 1902. Telescopic comets, however,

are very numerous, and a year never passes without one or more being discovered. The ordinary periodic comets, such as Encke's, Faye's, and others, are very faint, and are becoming fainter at each return—a clear proof that comets die, as Kepler said three centuries ago. This brings us to the subject of the next chapter, Meteoric Astronomy.

CHAPTER VIII.

METEORS.

THERE is no more interesting chapter in the history of astronomy than that relating to meteors. A hundred years ago shooting-stars were not considered to be astronomical phenomena. They were supposed to be merely inflammable vapours which caught fire in the upper regions of our atmosphere, although both Halley and the scientist *Ernst Chladni* (1756-1827) had notions of their celestial origin. For thirty-three years after the beginning of the century, however, nothing was heard of meteoric astronomy, nor was the subject considered as part of the astronomer's labours.

A great meteoric shower took place on the night of November 12 and morning of November 13, 1833. The shower was probably the grandest ever witnessed, the shooting-stars being literally innumerable. The display was best observed in America, and was attentively

watched by *Denison Olmsted* (1791-1859), Professor of Mathematics at Yale, and by the American physicist, *A. C. Twining* (1801-1884). These investigators discovered that all the meteors which fell during the great shower seemed to come from the same part of the celestial vault. In other words, their paths, when traced back, were found to converge to a point near the star γ Leonis. This observation gave the death-blow to the theory of their terrestrial origin. The point known as the "radiant" was clearly a point independent of the Earth. Olmsted also recognised the fact that the shower had taken place in the previous year, and he regarded it as produced by a swarm of particles moving round the Sun in a period of 182 days. Soon after this it was noticed that the phenomenon took place in 1834 and subsequent years with gradually decreasing intensity. It was then remembered that Humboldt had observed in November 1799 a very brilliant shower, and accordingly Olbers suggested that another shower might be seen in 1867.

The falling stars of August were next proved by *Adolphe Quetelet* (1791-1874) to form another meteoric system; and accordingly the theory of Olmsted that the November meteors moved round the Sun in 182 days had to be abandoned,

for, says Miss Clerke, "If it would be a violation of probability to attribute to *one* such agglomeration a period of an exact year or sub-multiple of a year, it would be plainly absurd to suppose the movements of *two* or more regulated by such highly artificial conditions." Accordingly Erman suggested in 1839 the theory that meteors revolved in closed rings, intersecting the terrestrial orbit; and that when the Earth crossed through the point of intersection, it met some members of the swarm. The subject now remained in abeyance for thirty-four years, if we except some wonderful ideas put forward in 1861 by *Daniel Kirkwood* (1813-1896), an American astronomer, who stated his belief in the disintegration of comets into meteors; but little attention was paid to his opinions. In 1864 the subject was taken up by *Hubert Anson Newton* (1830-1896), Professor at Yale, who undertook a search through ancient records for the thirty-three-year period of the Leonids or November meteors. His search was highly successful, and having demonstrated the existence of the period, Newton set himself to determine the orbit. He indicated five possible orbits for the swarm, ranging from 33 years to 354½ days. Newton was unable to solve the question mathematically; but here Adams, the discoverer of Neptune, came to the

rescue, and demonstrated that the period of 33¼ years was alone possible, and that the others were untenable. These investigations, completed in March 1867, proved the existence of a great meteoric orbit extending to the orbit of Uranus.

Meanwhile Newton had predicted a meteoric shower on the evening of November 13 and morning of November 14, 1866. His prediction was fulfilled. The shower was inferior to that of 1833, but was still a magnificent spectacle. Sir Robert Ball, then employed at Lord Rosse's Observatory, observed the shower, and records the impossibility of counting the meteors. This great shower attracted the attention of astronomers all over the world to the study of meteors. Meanwhile Schiaparelli had been working at the subject for some time, and in four letters addressed to Secchi, towards the end of 1866, he showed that meteors were members of the Solar System, possessed of a greater velocity than that of the Earth, and travelling in orbits resembling those of comets, in the fact that they moved in no particular plane, and that their motion was both direct and retrograde. Schiaparelli computed the orbit of the Perseids or August meteors, and was astonished to find it identical with the comet of August 1862. This was a proof of the connection between these two apparently widely

different types of celestial bodies. Early in 1867 Schiaparelli found that Le Verrier's elements for the orbit of the Leonids were identical with those of the comet of 1866, discovered by *Ernst Tempel* (1821 - 1889). Peters of Altona had meanwhile reached the same conclusion; while *Edmund Weiss* (born 1837) of Vienna pointed out the similarity of the orbit of a star-shower on April 20 and that of the comet of 1861. He also drew attention, independently of Galle and D'Arrest, to the close connection between the orbits of the lost Biela's comet and the Andromedid meteors of November.

All doubt as to the connection of comets and meteors was removed by the great shower on November 27, 1872. Biela's lost comet was due at perihelion in 1872, and although searched for was not observed; but when the Earth crossed its orbit, a great meteoric shower took place. "It became evident," says Miss Clerke, "that Biela's comet was shedding over us the pulverised products of its disintegration." The shower was little inferior to that of 1866. Meanwhile *Ernst Klinkerfues* (1827 - 1884), Professor at Göttingen, believing that Biela's comet itself had encountered the Earth, telegraphed to *Norman Robert Pogson* (1829-1891), Government astronomer at Madras, to search for the comet in the

opposite region of the sky. Pogson did observe a comet, but certainly not Biela's, although probably another fragment of the missing body.

The theory of the actual disintegration of comets was enunciated by Schiaparelli in 1873, and developed in his work 'Le Stelle Cadenti.' He was led to regard comets as cosmical clouds formed in space by "the local concentration of celestial matter." He then remarks that a cosmical cloud seldom penetrates to the interior of the Solar System, "unless it has been transformed into a parabolic current," which may occupy years, or centuries, in passing its perihelion, "forming in space a river, whose transverse dimensions are very small with respect to its length: of such currents, those which are encountered by the earth in its annual motion are rendered visible to us under the form of showers of meteors diverging from a certain radiant."

Schiaparelli next pointed out that when the current of meteors encounters a planet, the resulting perturbations cause some of the meteoric bodies to move in separate orbits, forming the bolides and aerolites which fall from the sky at intervals. "The term *falling stars*," he says, "expresses simply and precisely the truth respecting them. These bodies have the same

relation to comets that the small planets between Mars and Jupiter have to the larger planets." In the third chapter of his 'Le Stelle Cadenti' he explicitly states that "the meteoric currents are the products of the dissolution of comets, and consist of minute particles which certain comets have abandoned along their orbits, by reason of the disintegrating force which the Sun and planets exert on the rare materials of which they are composed."

In 1878 *Alexander Stewart Herschel* (born 1836), son of Sir John Herschel, and a famous meteoric observer, published a list of known or suspected coincidences of meteoric and cometary orbits, amounting to seventy-six. Meanwhile much progress has since been made in the observation of meteoric showers and the determination of their radiant points. In this branch of astronomy, by far the greatest name is that of William Frederick Denning, the self-made English astronomer. Born at Redpost, in Somerset, in 1848, his career of meteoric observation commenced in 1866. For the past forty years he has attentively devoted himself to the observation of meteors. From 1872 to 1903 he determined the radiant points of no fewer than 1179 meteoric showers. In addition to this, he published, in 1899, a

catalogue of meteoric radiants, containing 4367; and he has carefully studied the remarkable objects known as fireballs or "sporadic meteors." He has occasionally been able to trace a connection between fireballs and weak meteoric showers, but he concludes that they "must either be merely single sporadic bodies, or else the survivors of some meteor group, nearly exhausted by the waste of its material during many past ages." All of Denning's meteoric work has been done in his spare time, for it must be borne in mind that he pursues the profession of accountant in Bristol, and that only his leisure hours have been devoted to the science of astronomy. His researches have been entirely conducted with the unaided eye. His only instrument is a perfectly straight wand, which he uses as a help and corrective to the eye in ascribing the paths of the meteors. Thanks to the laborious work of this able English astronomer, the observation of meteors is now a *scientific* branch of astronomy. In the words of Maunder, "for six thousand years men stared at meteors and learned nothing, for sixty years they have studied them and learned much, and half of what we know has been taught us in half that time by the efforts of a single observer."

Further meteoric showers from Biela's comet were seen in 1885 and 1892. The Leonid shower was confidently predicted for 1899, in accordance with the thirty-three-year period, but the great display did not come off, either in 1899 or 1900. In 1901 there was a certain weak shower observed in America; and similar displays took place in 1903 and 1904. Many explanations have been given as to the failure of the shower, the most probable idea being that the attraction of Jupiter diverted the meteors from their course.

Denning's observations on meteors resulted, as early as 1877, in the discovery of so-called "stationary radiants." The radiant-point of a long enduring shower usually exhibits an apparent motion, resulting from the combined orbital motions of the Earth and the meteors; but Denning found that in some cases the shower, though lasting for months, persistently exhibited the same radiant-point, implying that the motion of the Earth must be insignificant compared with that of the meteors, computed by Ranyard at 880 miles per second. The difficulty of admitting so great a velocity led the French astronomer, *François Felix Tisserand* (1845-1896), to doubt the existence of these stationary radiants; but the fact of their

existence cannot be doubted, although no really satisfactory explanation has been offered.

Another type of meteors comprises the bodies termed respectively as bolides, uranoliths, and aerolites,—stones which fall to the Earth from the sky. In 1800 the French Academy declared the accounts of stones having fallen from the heavens to be absolutely untrue. Three years later an aerolite fell at Laigle, in the Department of Orne, on April 26, 1803, attended by a terrific explosion. In the words of Flammarion, "Numerous witnesses affirmed that some minutes after the appearance of a great bolide, moving from south-east to north-east, and which had been perceived at Alençon, Caen, and Falaise, a fearful explosion, followed by detonations like the report of cannon and the fire of musketry, proceeded from an isolated black cloud in a very clear sky. A great number of meteoric stones were then precipitated on the surface of the ground, where they were collected, still smoking, over an extent of country which measured no less than seven miles in length."

Some aerolites, instead of being shattered into fragments, have been observed to fall to the Earth intact, and bury themselves in the ground. Numerous instances have been observed during the last century, and masses of meteoric stones

have been found in positions which clearly indicate that they must have fallen from the sky. Chemists have made analyses of the elements in these remarkable bodies, and have found them to contain iron, magnesium, silicon, oxygen, nickel, cobalt, tin, copper, &c. The spectrum of these aerolites, raised to incandescence, has been studied by Vogel and by the Swedish observer, *Bernhard Hasselberg* (born 1848), who detected the presence of hydrocarbons, which are also present in cometary spectra.

When the existence of aerolites as celestial bodies was first recognised, Laplace suggested that they had been ejected from volcanoes on the Moon. This theory, although supported by Olbers and other astronomers, was soon rejected. Next, it was suggested that they were ejected from the Sun, and Proctor believed them to come from the giant planets. A very detailed discussion of the subject is to be found in Ball's 'Story of the Heavens' (1886), in which he expresses views in harmony with those of the Austrian physicist Tschermak. Ball demonstrated that the meteors which fall to the Earth cannot have come from any other planet, nor from the Sun. Accordingly, he concluded that they were originally ejected by the volcanoes of the Earth many ages ago, when they were

active enough to throw up pieces of matter with a velocity great enough to carry them away from the Earth altogether. Such meteors would, however, intersect the terrestrial orbit at each revolution.

The alternative theory to this, supported by Schiaparelli and Lockyer, is that the aerolites are merely larger members of the meteor-swarms, which have been deflected from their paths. The chief objection to this theory is the absence of connection between the meteoric showers and the falls of aerolites and bolides. Only on one occasion was a meteoric stone observed to fall during a shower. On November 27, 1885, during the shower of Andromedid meteors from Biela's comet, a large bolide, weighing more than eight pounds, fell at Mazapil, in Mexico. This, however, was the only case hitherto observed; and it may have been merely a coincidence.

CHAPTER IX.

THE STARS.

THE most remarkable progress in astronomy during the past century has been in the department of sidereal science, or the study of the Suns of space, observed for their own sakes, and not merely for the purpose of determining the positions of the Sun and Moon, and to assist navigation. Thanks to Herschel, the nineteenth century witnessed the steady development of stellar astronomy, combined with many important discoveries and investigations.

The one pre-Herschelian problem in sidereal astronomy was the distance of the stars. Owing to its bearing on the Copernican theory, the problem was attacked by the astronomers of the seventeenth and eighteenth centuries. Herschel made numerous attempts to detect the parallax of the brighter stars, but failed. Meanwhile there had been many illusions. Piazzi believed that his instruments—which in reality were

worn out and unfit for use — had revealed parallaxes in Sirius, Aldebaran, Procyon, and Vega; Calandrelli, another Italian, and *John Brinkley* (1763-1835), Astronomer-Royal of Ireland, were similarly deluded; and in 1821 it was shown by *Friedrich Georg Wilhelm Struve* (1793-1864), the great German astronomer, that no instruments then in use could possibly be successful in measuring the stellar parallax. A few years later, however, Fraunhofer brought the refractor to a degree of perfection surpassing all previous efforts. In 1829 he mounted for the observatory at Königsberg a heliometer, the object-glass of which was divided in two, and capable of very accurate measurements. This heliometer eventually revealed the parallax of the stars in the able hands of Friedrich Wilhelm Bessel.

Friedrich Wilhelm Bessel was born at Minden, on the Weser, south-west of Hanover, on July 22, 1784. His father was an obscure Government official, unable to provide a university education for his son. Bessel's love of figures, together with an aversion to Latin, led him to pursue a commercial career. At the age of fourteen, therefore, he entered as an apprenticed clerk the business of Kuhlenkamp & Sons, in Bremen. He was not content, however, to remain in that humble position. His great

ambition was to become supercargo on one of the trading expeditions sent to China; and so he learned English, Spanish, and geography. But he never became a supercargo. In order to be fully equipped for such a position, he determined to learn how to take observations at sea, and his acquaintance with observation aroused a desire to study astronomy. He constructed for himself a sextant, and by means of this, along with a common clock, he determined the longitude of Bremen.

Such enthusiasm could not be long without its reward. For several years Bessel remained a clerk, and the hours devoted to study were those spared from sleep. He studied the works of Bode, Von Zach, Lalande, and Laplace, and in two years was able to compute the orbits of comets by means of mathematics. From some observations of Halley's comet at its appearance in 1607, Bessel calculated its orbit, and forwarded the calculation to Olbers, then the greatest authority on cometary astronomy. Olbers was delighted at this work, and he sent the results to Von Zach, who published them. The self-taught young astronomer had accomplished a piece of work which fifteen years before had taxed the skill and patience of the French Academy of Sciences.

In 1805, Harding, Schröter's assistant at Lilienthal, resigned his position for a more promising one at Göttingen. Olbers procured for Bessel the offer of the vacant post, which the latter accepted. At Lilienthal Bessel received his training as a practical astronomer. He remained in Schröter's observatory until 1809. Although only twenty-five years of age, he had become so well known in Germany that in that year he was appointed Professor of Astronomy in the University of Königsberg, and was chosen to superintend the erection of the new observatory there. Within a few years a clerk in a commercial office had worked his way from obscurity to fame.

In 1813 the Königsberg Observatory was completed, and here Bessel worked for thirty-three years, until his death, on March 17, 1846. It was only about ten years before his death that he commenced his search for the stellar parallax, with the aid of Fraunhofer's magnificent heliometer. He determined to make a series of measures on a small double star of the fifth magnitude in the constellation Cygnus, named 61 Cygni, the large proper motion of which led him to suspect its proximity to the Solar System. From August 1837 to September 1838 he made observations on 61 Cygni, and he found that

there was an annual displacement which could only be attributed to parallax. In order to have no mistake, he made another year's observations, which confirmed the results he arrived at previously, and all doubt was removed by a third series. The resulting parallax was 0·3483″, corresponding to a distance of 600,000 times the Earth's distance from the Sun. This was confirmed some years later by C. A. F. Peters at Pulkowa, and still later by Otto Struve, who estimated the distance at forty billions of miles. Meanwhile, F. G. W. Struve, working at Pulkowa, found a parallax of 0·2613″ for Vega, but this was afterwards found to be considerably in error. Accordingly, Struve does not rank with Bessel as a successful measurer of star-distance. But independently of Bessel, another accurate measure had been made by *Thomas Henderson*, the great Scottish astronomer.

Born in Dundee in 1798, Thomas Henderson was the youngest of five children of a hard-working tradesman. After education in his native town he went to Edinburgh, where he worked for years as an advocate's clerk, pursuing studies in astronomy as a recreation from his boyhood. In 1831 he had become so well known, that he received the appointment of Astronomer-Royal at the new observatory at

the Cape of Good Hope. But the climate of South Africa did not suit his health, and after a year he returned to Scotland. In 1834 he became Professor of Astronomy in the University of Edinburgh, and Astronomer-Royal of Scotland, which position he held till his death on November 23, 1844, at the early age of forty-six.

During a year's work at the Cape, Henderson undertook a series of observations on the bright southern star, α Centauri, with a view to determining its parallax. These observations were made in 1832 and 1833, but were not reduced until Henderson's return to Scotland. At length, on January 3, 1839, he announced to the Royal Astronomical Society that he had succeeded in measuring the parallax of α Centauri, which he determined as about one second of arc, corresponding to a distance of about twenty billions of miles. This result was confirmed by the observations of *Thomas Maclear* (1794-1879), his successor at the Cape, and by those of later observers, notably Sir David Gill, who has reduced the parallax to $0{\cdot}75''$.

Other determinations of stellar parallax, some genuine and others illusory, were made soon after these successful observations. C. A. F. Peters

and Otto Struve at Pulkowa were among the most famous parallax-hunters in the middle of the century. One of the most successful searchers after parallax was the German astronomer *Friedrich Brünnow* (1821-1891), who was employed from 1865 to 1874 as Astronomer-Royal of Ireland. He determined the parallax of Vega as 0·13″, and this was confirmed in 1886 by Hall at Washington: while he measured the parallax of the star Groombridge 1830, which turned out to be 0·09″. He resigned his post in 1874, and his successor at Dublin Observatory proved to be his successor also in this branch of astronomy. *Robert Stawell Ball*, born in Dublin in 1840, was astronomer to Lord Rosse in 1865 and 1866, and became in 1874 Astronomer-Royal of Ireland in succession to Brünnow, a position which he filled until his appointment in 1892 as Professor of Astronomy at Cambridge, and director of the observatory there. During his term of office in Dublin he undertook, in 1881, a "sweeping search" for large parallaxes, thereby disproving certain ideas as to the proximity to the Earth of red and temporary stars; while he also determined the parallax of the star 1618 Groombridge.

But the greatest extension of our knowledge of stellar distances, in recent years, is due to a

Scottish astronomer, who has maintained the reputation of Scotland, and also of the Cape Observatory, in this line of research. Born in Aberdeen in 1843, *David Gill* directed Lord Lindsay's private observatory at Dunecht, in Aberdeenshire, from 1876 to 1879. In the latter year he succeeded *Edward James Stone* (1831-1897) as Astronomer-Royal at the Cape, a position which he has since filled with conspicuous ability. From 1881 he has been engaged in the hunt for parallax. In conjunction with *William Lewis Elkin* (born 1855), now director of Yale College Observatory, he determined the parallaxes of nine stars with the aid of Lord Lindsay's heliometer. In 1887, with a larger instrument, he resumed the search, while Elkin worked in co-operation with him, but at Yale Observatory, where he undertook the measurement of the parallaxes of northern stars. He fixed in 1888 an average parallax for first-magnitude stars, which was determined at 0·089″, corresponding to a journey for light of thirty-six years.

Most of the successful determinations of parallax have been made by the "relative" method—that is, the determination of the displacement of a star in reference to another star, assumed to be situated at an immeasurable distance.

The method of absolute parallax, on the other hand,—the star's displacement in right ascension and declination,—has been seldom used, owing to the laborious reduction which has to be gone through before the result can be reached. In 1885, however, a series of observations were undertaken at Leyden by *Jacobus Cornelius Kapteyn* (born 1851), who determined by the absolute method the parallaxes of fifteen northern stars.

The first application of photography to the problem was due to the zeal and energy of *Charles Pritchard* (1808-1893), Professor of Astronomy at Oxford, who determined by this method the parallax of 61 Cygni, which he announced in 1886 to be 0·438″, in agreement with Ball's determination. He also determined the average parallax of second-magnitude stars, which came out as 0·056″. Since the time of Pritchard's observations various other more or less satisfactory determinations of parallax have been made. Few of the parallax determinations are probably very accurate, and none exact; but an idea of the difficulty of the measurement may be gathered from the remark of an American writer, Mr G. P. Serviss, that the displacement "is about equal to the apparent distance between the heads of two pins, placed an inch apart, and

viewed from a distance of a hundred and eighty miles."

Closely allied to the question of parallax is the determination of the exact positions of the stars and the formation of star-catalogues. In this branch, too, much is due to the genius of Bessel. The observations of Bradley at Greenwich from 1750 to 1762 were reduced by Bessel into the form of a catalogue, which was published in 1818, with the title of 'Fundamenta Astronomiæ.' During the years 1821 to 1823 Bessel took 75,011 observations, by which he brought up the number of accurately known stars to 50,000. At the same time notable catalogues had been constructed, particularly by the English astronomer, *Francis Baily* (1774 - 1844), and by *Giovanni Santini* (1786-1877), director of the observatory at Padua; but Bessel's successor in this branch of research was *Friedrich Wilhelm August Argelander* (1799 - 1875). In 1821 he became assistant to Bessel at Königsberg, in 1823 director of the Observatory at Abo, in Finland, and in 1837 of that at Bonn. Here he commenced in 1852 the great 'Bonn Durchmusterung,' a catalogue and atlas of 324,198 stars visible in the northern hemisphere. The great catalogue was published in 1863. After Argelander's death it was extended so as to

include 133,659 stars in the southern hemisphere, by his assistant *Eduard Schönfeld* (1828-1891), who succeeded him in 1875 as director of Bonn Observatory, where he died in 1891. Meanwhile a greater undertaking was commenced in 1865 by the Astronomische Gesellschaft. This was the co-operation of thirteen observatories in Europe and America for the exact determination of the places of 100,000 of Argelander's stars.

In the southern hemisphere, working at Cordova in Argentina, was the great American astronomer, *Gould*, whose 'Uranometria Argentina,' published in 1879, gives the magnitudes of 8198 stars, and whose Argentine General Catalogue, containing reference of 32,448 stars, was published in 1886. The late Radcliffe observer, Stone, published a useful catalogue in 1880 from his observations at the Cape.

The application of photography to the work of star-charting dates from 1882, when Gill photographed the comet of 1882, and was struck with the distinctness of the stars on the background. For some time he had contemplated the extension of the 'Durchmusterung,' from the point where Schönfeld left it, to the southern pole, and the idea struck him to utilise photography for the purpose. In 1885, accordingly, Gill commenced work, and in four years all the

photographs were taken. The reduction of the observations into the form of a catalogue was spontaneously undertaken by the great Dutch astronomer, Kapteyn, who was occupied with the work for fourteen years, until in 1900 the great catalogue, known as the 'Cape Photographic Durchmusterung,' was completed. Half a million stars are represented on the plates taken at the Cape.

By the time the 'Durchmusterung' was completed, a greater undertaking was in progress. Paul and Prosper Henry, astronomers at the Paris Observatory, when engaged in continuing Chacornac's ecliptic charts, applied photography to their work, and found it very successful. Accordingly Gill's proposal, on June 4, 1886, of an International Congress of Astronomers, to undertake a photographic survey of the heavens, was enthusiastically received by the French astronomers. The Congress met at Paris in 1887, under the presidentship of *Amédée Mouchez* (1821-1892), director of the Paris Observatory, fifty-six astronomers of all nations being present. The Congress resolved to construct a Photographic Chart, and a Catalogue, the former containing twenty million stars, the latter a million and a quarter. Meetings were held in Paris in 1891, 1893, 1896, and 1900 to super-

intend the progress of the work, which is now (1906) well advanced towards completion.

A unique star catalogue is in course of preparation by the Scottish astronomer, *William Peck* (born 1862), astronomer to the City of Edinburgh since 1889. Mr Peck's catalogue is accompanied by a series of charts. His star-magnitudes are those of all famous catalogues reduced to a standard scale. This catalogue, the result of more than fifteen years' work, will be an important addition to the many valuable works of the kind already in existence, and will further increase the already great reputation of Scotsmen in practical astronomy.

The determination of the proper motions of the stars is another important branch of practical astronomy in which much progress has been made since the time of Herschel. Stars with much larger proper motions than those of the first magnitude have been discovered. For many years the small sixth-magnitude star in Ursa Major, 1830 Groombridge, was supposed to be the swiftest of the stars, and was named by Newcomb the "runaway star." But in 1897, on examining the plates of the 'Cape Durchmusterung,' Kapteyn discovered a still swifter star of the eighth magnitude, situated in the southern constellation, Pictor. The rate

of its motion is over eight seconds of arc yearly; and an idea of the vast distance of the stars may be obtained by the statement that it would take 200 years for the star—known as Gould's Cordova Zones, V Hour 243—to move over a space equal to the moon's diameter. Important observations have been made on the stellar motions, and on their bearing on the structure of the Universe, by various astronomers, including J. C. Kapteyn and *Ludwig Struve* (born 1858), son of Otto Struve; but these must be reserved for a later chapter.

Richard Anthony Proctor, born at Chelsea, in London, in 1837, graduted at Cambridge in 1860. For the next twenty-eight years he earned his living by publishing many volumes on astronomy, popular and technical, fifty-seven having appeared at the time of his death, which took place at New York on September 12, 1888. Notwithstanding the vast amount of work bestowed on his books, his original investigations were permanent contributions to astronomical science. In 1870 he undertook to chart the directions and amounts of 1600 proper motions. While engaged on this work, it occurred to him that it would be "desirable and useful to search for subordinate laws of motion." He found, from the laborious process of charting, that five of

the seven stars of the Plough had a motion in common—that is to say, were moving in the same direction at the same rate. This phenomenon was termed by Proctor "star-drift." He also recognised other instances of star-drift in other portions of the heavens.

The subject was soon afterwards taken up by the French astronomer, Camille Flammarion. Born in 1842 at Montigny-le-Roi, in Haute Marne, Flammarion was appointed assistant to Le Verrier in 1858, but gave up his post in 1862. Employed successively at the Bureau des Longitudes, and as editor of scientific papers, he founded in 1882 his private observatory at Juvisy-sur-Orge, where he has since continued his investigations.

Following up Proctor's discovery of star-drift, Flammarion drew charts of proper motions. He demonstrated the "common proper motion" of Regulus and an eighth-magnitude star, Lalande 19,749, from a comparison of his measures in 1877 with those of Christian Mayer a century previously; while he discovered many other instances. His reflections on these motions, as given in his 'Popular Astronomy,' are worthy of reproduction: "Such are the stupendous motions which carry every sun, every system, every world, all life, and all destiny in all

directions of the infinite immensity, through the boundless, bottomless abyss; in a void for ever open, ever yawning, ever black, and ever unfathomable; during an eternity, without days, without years, without centuries, or measures. Such is the aspect, grand, splendid, and sublime, of the universe which flies through space before the dazzled and stupefied gaze of the terrestrial astronomer, born to-day to die to-morrow, on a globule lost in the infinite night."

Measures of proper motion only enable us to determine the motion of stars across the line of sight. They do not tell us whether the star is advancing or receding. Here, however, the spectroscope comes to our aid by means of Doppler's principle, described in the chapter on the Sun. It occurred to Huggins that, by observing the displacement of the lines in the spectra of the stars, he could determine their motion in the line of sight. His first results were announced in 1868. In the case of Sirius, the displacement of the line marked F was believed to indicate a velocity of recession of 29 miles a second. Some time later Huggins announced that Betelgeux, Rigel, Castor, and Regulus were retreating, while Arcturus, Pollux, Vega, and Deneb were approaching. Soon after this successful work the

subject was taken up by Maunder at Greenwich and by Vogel at Bothkamp; but the delicacy of the measurements prevented satisfactory results from being reached through visual observations, and accordingly the measurements were very discordant.

In 1887 H. C. Vogel, working at Potsdam Astrophysical Observatory, applied photography to the measurement of radial motion. Assisted by *Julius Scheiner* (born 1858), he determined the radial motions of fifty-one bright stars by photographing the stellar spectra and measuring the photographs. Vogel found 10 miles a second to be the average velocity of stars in the line of sight, the tendency of the eye being to exaggerate the displacements. The swiftest of the stars measured by Vogel proved to be Aldebaran, with a velocity of recession of 30 miles a second. Since 1892 the subject has been pursued by Vogel himself with the new 30-inch refractor at Potsdam, by Campbell at the Lick Observatory, Bélopolsky at Pulkowa, and other observers. Towards the end of 1896 Campbell undertook, with the 36-inch Lick refractor, a series of measures on radial motion, and many important discoveries were made. These, however, must be reserved for the chapter dealing with double stars.

Herschel's great discovery, from the apparent motions of the stars, of the movement of the Solar System was not accepted by the next generation of astronomers. Bessel declared in 1818 that there was absolutely no evidence to show that the Sun was moving towards Hercules. Even Sir John Herschel rejected his father's views, although some confirmatory results had been reached by Gauss. At length, in 1837, Argelander, in a memorable paper, based on his observations at Abo, in Finland, attacked the problem, and demonstrated, from a discussion of the motions of 390 stars, quite independently of Herschel's work, that the Solar System was moving towards Hercules. This was confirmed in 1841 by Otto Struve, in 1847 by *Thomas Galloway*, and in 1859 and 1863 by Airy and *Edwin Dunkin* (1821-1898), assistant at Greenwich Observatory.

Meanwhile, in 1886, *Arthur Auwers*, permanent Secretary of the Berlin Academy of Sciences, completed the re-reduction of Bradley's observations at Greenwich, and brought out 300 reliable proper motions, which were utilised by Ludwig Struve, whose investigation removed the solar apex from Hercules to the neighbouring constellation Lyra: this slight change was confirmed by *Oscar Strumpe*, of Bonn, and *Lewis*

Boss (born 1847), director of the Observatory at Albany, New York. An investigation by Newcomb fully confirmed the previous results. In 1900, 1901, and 1902 Kapteyn made three distinct investigations on the solar motion, and still further confirmed the previous investigations.

These investigations are fully confirmed by the application to the question of Doppler's principle of measuring radial motion. The spectroscopic researches of Campbell at the Lick Observatory place the solar apex very near the position assigned to it by Newcomb and Kapteyn. Campbell finds the solar velocity to be about 12 miles a second, and Kapteyn thinks a velocity of about 11 miles a second is "the most probable value that can at present be adopted."

CHAPTER X.

THE LIGHT OF THE STARS.

"THAT a science of stellar chemistry should not only have become possible, but should already have made material advances, is assuredly one of the most amazing features in the swift progress of knowledge our age has witnessed." So writes Miss Agnes Mary Clerke, the historian of modern astronomy. As long ago as 1823 Fraunhofer observed the spectra of the brighter stars, and gathered the first hint of the grouping of the stars into three classes. Then, after Fraunhofer's death, the subject lay in abeyance for thirty-seven years. At length, in 1860, on Kirchhoff's explanation of the Fraunhofer lines, the study of stellar spectra was inaugurated at Florence by Donati, who carefully fixed the positions of the more important lines. His instrumental means, however, were very limited, and his observations were not successful. In 1862 Rutherfurd, in New York, commenced the study

of stellar spectra, but shortly afterwards turned his attention to astronomical photography. The actual founders of stellar spectroscopy were the eminent Italian observer, Angelo Secchi, and the illustrious Englishman, William Huggins.

Angelo Secchi was born in 1818 at Reggio, in the Emilia. Educated in the Collegio Romano, he was ordained priest in 1847, but his love of science, and particularly astronomy, dates from the beginning of his career. In 1849 he succeeded Di Vico as director of the Observatory of the Collegio Romano. This post he filled with conspicuous ability for a period of twenty-nine years, until his death on February 26, 1878. To Secchi is due the credit of the first spectroscopic survey of the heavens. He reviewed the spectra of 4000 stars, and classified them into four distinct groups, which are recognised to this day. The first type embraces over half of those which Secchi examined. This type is represented by Sirius, Vega, Altair, and other bluish-white stars, and is characterised by the intensity of the hydrogen lines. The second type embraces the yellow stars, such as Capella, Arcturus, Aldebaran, Pollux, and the Sun itself, and is known as the Solar type. The spectra of these stars closely resemble that of the Sun, and are distinguished by innumerable lines.

Secchi's third type, or red stars, represented by Betelgeux, Antares, and others, are characterised by strong absorption bands, and the spectra have been described as "fluted." The third-type stars are comparatively scarce compared with the first and second, and the fourth is even less numerous. The fourth-type stars are also red with broad absorption lines. To Secchi's four types a fifth was added in 1867 by Wolf and Rayet of Paris Observatory—namely, the gaseous stars. Secchi aimed at a comprehensive survey of the stellar spectra, and he accomplished much valuable work. He did not devote his time to analysing individual stars. This branch of study—analysis of spectra and the determination of the elements in the stars—was undertaken by his contemporary, William Huggins, one of the greatest astronomers whom England has ever produced.

Born in London in 1824, William Huggins commenced his astronomical researches at the age of twenty-eight. In 1856 he erected, at Tulse Hill, London, an observatory which he equipped at great expense. He commenced observations on the usual astronomical lines, taking times of transits and making drawings of the surfaces of the planets. But he soon tired of the routine of ordinary astronomical

work, and on the publication of Kirchhoff's explanation of the Fraunhofer lines in the solar spectrum, he commenced to investigate the spectra of the stars. Having constructed a suitable spectroscope, he commenced observations in 1862 in conjunction with his friend, William Allen Miller, Professor of Chemistry in London. He exhaustively investigated the two red stars, Betelgeux and Aldebaran, ascertaining the existence in the former star of sodium, iron, calcium, magnesium, and bismuth; and in the latter star the same elements, with the addition of tellurium, antimony, and mercury.

In 1863 Huggins made an attempt to photograph the spectra of the stars, and, indeed, obtained prints of Sirius and Capella, but no lines were visible in them. In 1874 Draper of New York obtained a photograph of the spectrum of Vega, showing four lines. Two years later Huggins again attacked the problem, and secured a photograph of the spectrum of Vega, showing seven strong lines. In 1879 he was enabled to communicate satisfactory results of his work to the Royal Society, and since then he has secured many admirable representations. In 1899 the monumental work, 'An Atlas of Representative Stellar Spectra,' the joint work of Sir William and Lady Huggins, was published.

In 1874 the German Government established at Potsdam the Astrophysical Observatory, for the spectroscopic study of the Sun and stars. A position on the staff was given to Hermann Carl Vogel, whose researches in astronomical spectroscopy rank with those of Secchi and Huggins. Born in Leipzig in 1842, he was from 1865 to 1869 employed in the Leipzig Observatory. Called to Bothkamp as director in 1870, he resigned his post in 1874 to accept a position on the staff at Potsdam Observatory. In 1882 he became director of that Institution, which position he still retains.

In 1874 Vogel revised Secchi's classification of stellar spectra, and in 1895 he further improved on it. His classification improves rather than supersedes the previous work of Secchi; nevertheless, he approached the question from a different standpoint. Vogel concluded in 1874 that a rational scheme of stellar classification "can only be arrived at by proceeding from the standpoint that the phrase of development of the particular body is, in general, mirrored in its spectrum." Vogel divides Secchi's first type into three classes. In the first type, designated I*a*,—represented by Sirius and Vega,—the metallic lines are "very faint and fine," and the hydrogen lines conspicuous. In I*b* no hydrogen lines are

visible, while in Ic the hydrogen lines are bright. This class includes the gaseous stars. In 1895, after the recognition of helium in the stars by his assistant, Scheiner, Vogel separated the stars of class I*b* from the first type altogether. These stars are sometimes designated as "Type O," and sometimes as helium stars and Orion stars, as the majority of the stars in Orion are of that type. The solar type is divided into two classes, II*a* being represented by the Sun, Capella, and other well-known stars, while II*b* includes the Wolf-Rayet stars. Secchi's third and fourth types are both classified by Vogel as of the third type. These red stars were specially studied from 1878 to 1884 by Dunér at Lund. His results were published in a descriptive catalogue which appeared at Stockholm in 1884. His researches related to the spectra of 352 stars, 297 of Secchi's third type and 55 of his fourth. Dunér is perhaps the greatest authority on stars with banded spectra.

Vogel's classification of spectra is generally adopted by astronomers, although others have been proposed by Lockyer and by *Edward Charles Pickering* (born 1846), director of the Harvard Observatory. Lockyer's classification was designed to fit in with his "meteoritic hypothesis," discussed in the chapter on Celestial Evolution.

The stars were divided by Lockyer into seven groups, according to his views of their temperature, rising through gaseous stars, red stars of Secchi's third type, and a division of solar stars to the Sirian type, and falling through a second division of the solar type to red stars of Secchi's fourth type.

The first spectroscopic star-catalogue was published in 1883 by Vogel, assisted by *Gustav Müller* (born 1851), a son-in-law of Spörer. The catalogue contained details of 4051 stars to the seventh magnitude, and more than half of these proved to be of Secchi's first type. Vogel's work was completed in different latitudes by Dunér at Upsala, and by *Nicolaus Thege von Konkoly* (born 1842) at O'Gyalla in Hungary.

The famous 'Draper Catalogue' ranks as the greatest catalogue of stellar spectra. It was undertaken at Harvard Observatory by E. C. Pickering, in the form of a memorial to Henry Draper, the successful spectroscopist. Commenced in 1886, and published in 1890, it contains photographs of the spectra of no fewer than 10,351 stars, down to the eighth magnitude. Pickering subdivided Secchi's types into various classes, the first or Sirian into four classes, the second into eight, while the third and fourth types each constitute a separate class. Pickering

designated his classes by the capital letters of the alphabet.

Much useful work has been done also in the analysis of the various spectra. Julius Scheiner, now "chief observer" at Potsdam Astrophysical Observatory, has, since 1890, done much valuable work in this direction. Special attention was devoted to the spectrum of Capella, 490 lines in the spectrum of which were measured by Scheiner. In his own words, "he believes a complete proof of the absolute agreement between its spectrum and that of the Sun to be thereby furnished." Other stars of the Sirian and solar classes were exhaustively studied by Scheiner.

The study of the exact brilliance of the stars was a branch of research long neglected, yet it is of much importance in astronomy, for it is only through exact measurement of stellar brilliance that stellar variation can be detected. Herschel commenced the study, which was continued by his son at the Cape, but it is only within the last twenty years that stellar photometry has become a recognised branch of astronomy; and the credit of this is due to the energy and zeal of the great American observer, Edward Charles Pickering.

Born in Boston in 1846, Edward Charles Pickering was appointed in 1865 Instructor of

mathematics in the Lawrence Scientific School at Harvard, after a distinguished university career. In 1876 he succeeded Winlock as director of the Harvard Observatory, and in the following year he commenced his photometric studies. He invented an instrument named the meridian photometer, with the aid of which he succeeded in determining, in the years 1879 to 1882, the exact brilliance of 4260 stars to the sixth magnitude between the north celestial pole and thirty degrees of south declination. At a later date he devised a larger photometer, with which he made over one million observations. Pickering next extended his survey to the southern hemisphere, erecting the photometer on the slope of the Andes, where the Harvard auxiliary station at Arequipa is now located, and where 8000 determinations of stellar brilliance were made. Meanwhile Pritchard, at Oxford, published in 1885 his 'Uranometria Nova Oxoniensis,' with photometric determinations of the brilliance of 2784 stars from the pole to ten degrees of south declination. Both of these catalogues were epoch-making works, and testify to the enthusiasm and perseverance of the astronomers who designed them.

The study of stellar photometry glides into that of stellar variation. At the beginning of

the nineteenth century the number of known variable stars was very small, as a glance at the list given in Brewster's edition of Ferguson's Astronomy (1811) will show. Some remarkable investigations were due to the English astronomer, *John Goodricke* (1764-1786), who rediscovered the variability of the star Algol, and accurately determined its period in 1782. Goodricke suggested that the regular variations in the light of Algol were due to the partial eclipse of its light by a dark satellite, a hypothesis now fully confirmed. Two years later, in 1784, Goodricke discovered other two variables, δ Cephei and β Lyræ. He died in 1786 at the age of twenty-one, and thus variable-star astronomy was deprived of its founder.

The foundation of variable-star astronomy as an exact branch of the science is due to Argelander. In the years 1837-1845, while residing at Bonn during the erection of the observatory, of which he had been made director, he erected a temporary observatory, and there he carefully determined the magnitudes of all stars visible in Central Europe. From this he was led to the discussion of stellar variation, to which subject he continued to give much attention. He was the first to describe a method of observing variable stars scientifically and accurately,—a

method consisting in estimating in "steps" or "grades" the difference in brilliance between the variable, or suspected variable, and other stars which are selected for comparison, and which are of various degrees of brilliance, so that they may be available for comparison with the variable throughout its fluctuations. Argelander's "steps" are tenths of a magnitude, and Gore describes the method of observation as follows: "If we call *a* and *b* the comparison stars, and *v* the variable, *a* being brighter than *b*, and if *v* is judged to be midway in brightness between *a* and *b*, we write *a*5*v*5*b*. If *v* is slightly nearer to *b*, we write *a*6*v*4*b*. We may also write *a*3*v*7*b*, or *a*7*v*3*b*, the sum of the steps being always ten."

This method, described in 1844, led to many discoveries at Bonn in the following twenty years by Argelander and his assistants Schmidt and Schönfeld. At this time Eduard Heis (1806-1877), at Münster, who also ranks as one of the founders of meteoric astronomy, while engaged on the construction of his great atlas, attentively determined the change of magnitude of stars visible to the naked eye; and by means of the naked eye, the opera-glass, and a small telescope, he amassed a large number of observations. At the same time two English observers,

Hind and Pogson, were making remarkable discoveries which greatly increased the number of known variables. Among Hind's discoveries were S Cancri of the Algol type; while Schmidt discovered another of the same class, δ Libræ, and also the famous ζ Geminorum. While director of the Observatory of Mannheim, an institution equipped with very antiquated instruments, Schönfeld devoted himself to the study of variable stars, and increased the number of known variables considerably. In the southern hemisphere Gould, in South America, did for the observation of variable stars what Argelander did in the northern.

In 1874 a very important, although not so obvious, service to variable-star astronomy was rendered by the Danish observer, *Hans Carl Fredrik Christian Schjellerup* (1827-1887). He translated from Arabic into French the works of the Persian astronomer of a thousand years ago, Al-Sufi, and thus rendered his observations available to modern astronomers. Al-Sufi was a most accurate observer, and, by comparing his catalogue with those of modern observers, it can be found whether stars have changed in brilliance during the past thousand years.

The study of variable stars has been pursued in recent years by many astronomers, both by

means of photography and by the visual method. The most important names in the visual discovery of variables are Gustav Müller and *Paul Friedrich Ferdinand Kempf* (born 1856) of Potsdam; *Alexander William Roberts* of Lovedale, South Africa; Seth Carlo Chandler of Boston; Nils Christopher Dunér at Upsala; and *John Ellard Gore* (born 1845) in Dublin.

The researches of J. E. Gore are a brilliant example of how much may be done for astronomy by means of very moderate instruments. Born in 1845 at Athlone, in Connaught, he went to India in 1868 as engineer on the Sirhind Canal in the Punjab. While in India he erected his small telescopes on brick pillars, and took observations, many of them of stellar brilliance. In 1879 he returned to Ireland, and since then has devoted himself to astronomy with zeal and enthusiasm. His discoveries and investigations of variables have been made by means of the binocular. On December 13, 1885, he discovered a remarkable star in Orion, which was at first considered to be temporary, and called "Nova Orionis," but was afterwards found to be a long-period variable star.

Recently photography has come much to the front in the discovery of variable stars. Pickering at Harvard, and Wolf at Heidelberg, have

particularly distinguished themselves in this branch, and the number of known variables is now very large, as every year brings fresh discoveries, mostly by aid of photography. Many of these newly-discovered variables are in star-clusters and nebulæ.

Pickering proposed in 1880 the following classification of variable stars, which has been adopted all over the scientific world: Class I., temporary star; Class II., stars undergoing in several months large variations, such as Mira Ceti and U Orionis; Class III., irregular variables, such as Betelgeux and α Herculis; Class IV., short-period variables, such as δ Cephei, ζ Geminorum, and β Lyræ; Class V., "Algol variables," which undergo variations lasting but a few hours. It is doubtful whether new stars should be included in a classification of variables, although in one case, at least, a new star was found to be a long-period variable. To these a sixth class may now be added. This class, the detection of which is mainly due to the profound investigations of Gore, is composed of what have been termed "secular variables," which undergo slow fluctuations in periods of many years, and sometimes of centuries. This Class includes δ Ursæ Majoris, Al-Fard, λ Draconis, θ Serpentis, ϵ Pegasi,

83 Ursæ Majoris, ζ Piscis Australis, β Leonis, α Ophiuchi, η Crateris, and others. The secular variations of some of these stars have been detected by Gore himself during the past thirty years, while in other cases he has detected them by comparison of the most important star-catalogues, from Hipparchus and Al-Sufi down to our own time. In some cases the star in question seems to be slowly gaining in brilliance, in others slowly diminishing.

Thanks to the application of the spectroscope, much is now known of the cause of the light changes in variable stars. Goodricke's theory of the variations of Algol was theoretically confirmed by the researches of E. C. Pickering in 1880. In 1889 Vogel proved beyond a doubt that the variation in the light of Algol is due to the partial eclipse of its light by a dark satellite. It was obvious to Vogel that, as both Algol and its companion are in revolution round their common centre of gravity, the motion of Algol in the line of sight might be detected by the spectroscopic method of observation. Vogel found that before each eclipse Algol was retreating from our system, while on recovering it gave signs of rapid approach, proving conclusively that both the star and its dark satellite were in revolution round their centre of gravity,—Algol

suffering partial eclipse only because the plane of the orbit lies in our line of sight. Algol, therefore, is not inherently a variable star, but merely a binary. Following up his researches, Vogel, assuming that the bright and dark stars are of equal density, arrived at the conclusion that Algol is a globe about one and a half million miles in diameter, the satellite equalling the size of the Sun, and the centres of the stars being separated by about 3,230,000 miles. Thus, star-variables of the Algol type are not variable in the true sense of the word. Even the most irregular of the Algol variables have been explained. Perhaps the most irregular was Y Cygni, discovered by Chandler in 1886. It was soon found, however, that the variations recurred with great irregularity: in less than two years the phases differed by as much as seven hours from the predicted times. At length the subject was taken up by Dunér at Upsala. A series of observations made with the 14-inch refractor at Upsala in 1891 and 1892 convinced him in the latter year that two eclipses take place in the course of one revolution: one star occults the other. Dunér showed that the intervals between minima were thus—1 day 9 hours; 1 day 15 hours; 1 day 9 hours, and so on. Thus, the first, third, fifth, and seventh sets of minima

obeyed a different law from the second, fourth, sixth, and eighth. Dunér proved that two stars revolve round their centre of gravity in less than three days, alternately occulting each other, while the ellipticity of the orbit explains the irregularity of the light changes. In April 1900 Dunér gave his final conclusions as follows: "The variable star Y Cygni consists of two stars of equal size and equal brightness, which move about their common centre of gravity in an elliptical orbit, whose major axis is eight times the radius of the stars." He also stated the exact period of revolution and the eccentricity of the orbit.

In the case of the short-period variables, such as β Lyræ, δ Cephei, ζ Geminorum, and η Aquilæ, the variations do not seem to be due to eclipse. It was discovered by Professor Pickering that β Lyræ is a spectroscopic binary, but Vogel and Keeler showed that the supposed orbit is incompatible with the eclipse theory. Vogel says: "I am convinced that β Lyræ represents a binary or multiple system, the fundamental revolutions of which in 12 days 22 hours in some way control the light change." The eclipse theory, however, is still maintained by Bélopolsky, who has framed a hypothesis according to which the chief minimum

of the star's light corresponds with the obscuration of the lesser star, the lesser minimum with that of the primary, implying that the primary is much less luminous in proportion to its light than its satellite,—a state of affairs which Miss Clerke concludes to be improbable.

The variable stars, δ Cephei and η Aquilæ, were both found in 1894 by Bélopolsky to be binaries; but as the times of minimum light do not correspond with those of eclipses in the hypothetical orbits, he concludes that the variations cannot be explained on the eclipsing satellite theory. Miss Clerke is inclined to the theory that the increase of luminosity in short-period variables is due to tidal action, so that while the revolutions of the stars control their variability, they are inherently unstable in light. A large number of these stars are known, and it is a remarkable fact that the majority of these variables lie on or near the Galaxy, so that their variations have probably something to do with their vicinity.

We now come to the long-period variables of which Mira Ceti, χ Cygni, and U Orionis are examples. Although varying in regular periods, generally of about a year, they are subject to remarkable irregularities, so that an exact period cannot be assigned even to Mira Ceti, of which

the maxima are at times retarded and at others accelerated with no apparent law. The spectroscopic investigations of Campbell in 1898 have shown that Mira Ceti is a solitary star, while bright lines of hydrogen appear in its spectrum at maximum, showing that the variations are due to periodical conflagrations in its atmospheres. In many other long-period variables bright lines have been observed.

A remarkable fact regarding these stars is the amount of their light change. Mira Ceti, for instance, varies from the first to the ninth magnitude, and U Orionis from the sixth to the twelfth. As M. Flammarion says, "the longer the period the greater the variation." Another remarkable fact is that their light curves show a curious resemblance to the curves of the solar spots, only on a vastly greater scale, which indicates that, relatively, these long-period variables are much older than our Sun, the small variations in the light of which are imperceptible. "Here, if anywhere," says Miss Clerke, "will be found the secret of stellar variability."

To the irregular variables no period can be assigned. Betelgeux, in Orion, the variation of which was noted by Sir John Herschel in 1840, is a typically irregular variable. But the most extraordinary of all variables is η Argus, in

the southern hemisphere, which is probably a connecting link between variable and temporary stars. The traveller Burchell, from 1811 to 1815, observed the star as of the second magnitude, but in 1827 he noted it to be of the first magnitude. In the following year it fell to the second magnitude. In 1834 Sir John Herschel noted the star to be between the first and second magnitude, and in 1838 it rose to the first, being equal to α Centauri. After a decline, it became in 1843 equal to Canopus, and not much inferior to Sirius. Then it began to fade, and in 1868 it was only of the sixth magnitude. In 1899 Innes estimated it as 7·71. Rudolf Wolf suggested a period of 46 years, and Loomis 67 years; but astronomers generally agree with Schönfeld that the star has no regular period.

The first temporary star of the nineteenth century was discovered by Hind, in London, April 28, 1848. It was of the fifth magnitude at maximum, and soon after began to fade, falling to the tenth magnitude. In 1860 a new star appeared in the cluster Messier 80 in Scorpio, and was discovered by Auwers at Königsberg. It reached only the seventh magnitude.

On the night of May 12, 1866, a new star of the second magnitude blazed out in the constellation Corona Borealis. It was first observed

at Tuam, in Ireland, by the Irish astronomer, *John Birmingham.* Four hours earlier Schmidt had been observing that part of the heavens, and it was not then visible. Birmingham at once communicated the discovery to Huggins, at Tulse Hill, who had commenced his spectroscopic observations. On May 16 Huggins observed its spectrum. In the words of Miss Clerke, "The star showed what was described as a double spectrum. To the dusky flutings of Secchi's third type, four brilliant rays were added. The chief of these agreed in position with lines of hydrogen; so that the immediate cause of the outburst was plainly perceived to have been the eruption, or ignition, of vast masses of that subtle kind of matter." Nine days after the appearance of the new star it was invisible to the naked eye, and afterwards fell to the tenth magnitude. In 1856 Schönfeld had observed it at Bonn as a telescopic star, so that it was not a "new star" in the true sense of the word.

The next temporary star observed was discovered by Schmidt, at Athens, November 24, 1876. It was of the third magnitude, situated in the constellation Cygnus. On December 2 its spectrum was examined at Paris by *Alfred Cornu* (1841-1902), and some days later at

Potsdam by Vogel and Lohse. It was closely similar to that of the new star of 1866, bright lines of hydrogen and other elements standing out in front of an "absorption" spectrum. By the end of 1876 the star was of the seventh magnitude. On September 2, 1877, Nova Cygni was observed at Dunecht, and its spectrum was found to have been transformed into that of a planetary nebula. Three years later, however, the ordinary stellar spectrum reappeared.

A new star appeared in the centre of the great nebula in Andromeda in August 1885. The first announcement of the discovery was by *Karl Ernst Albrecht Hartwig* (born 1851), who observed the new star on August 31; but it had been previously seen by several other observers. On September 1 it was of the seventh magnitude, and by March of the following year had fallen to the sixteenth. Observed by Vogel, Young, and Hasselberg, the new star gave a continuous spectrum, but Huggins and Copeland succeeded in discerning bright lines. Hall, at Washington, undertook a series of measures to detect the parallax of Nova Andromedæ, but his efforts were unsuccessful.

The discovery of the next temporary star was announced February 1, 1892, by the Rev. *Thomas*

D. Anderson, a Scottish amateur astronomer, in a post-card to the Astronomer-Royal of Scotland. The star was situated in the constellation Auriga. An examination of photographs, taken at Harvard Observatory, showed that the new star had appeared December 10, 1891, and had risen to a maximum of the fourth magnitude ten days later. On a photograph taken by Max Wolf on December 8 the new star was not visible. After Anderson's visual discovery, the spectrum of the new star was studied by Copeland, Huggins, Lockyer, Vogel, Campbell, and others. Bright hydrogen lines were visible in the spectrum, which appeared to be actually double, giving support to the theory that the outburst was the result of a collision between two dark bodies; and this was confirmed by the measurements of radial motion by the Potsdam astronomers.

After March 9, 1892, the new star steadily faded, falling to the sixteenth magnitude on April 26. But on August 17 *Edward Singelton Holden* (born 1846), director of the Lick Observatory, and his assistants, Schaeberle and Campbell, found it of the tenth magnitude. On August 19 Barnard found it transformed into a planetary nebula: while various spectroscopic

observations of the revived Nova revealed the nebular lines. By the end of 1894 the new star had faded to the eleventh magnitude, and early in 1901 was observed as a minute nebula.

After 1892 several new stars appeared, and were detected on photographic plates by *Mrs Fleming* (born 1857), of Harvard Observatory. The first of these, in the southern constellation Norma, was discovered in 1893 by its peculiar spectrum on a Draper spectrographic plate taken at Harvard. But the new star rose only to the seventh magnitude. Other new stars were discovered in Carina (Argo) in 1895, in Centaurus in 1895, in Sagittarius in 1898, and in Aquila in 1900. Nova Sagittarii was, at its brightest, fully equal to Nova Aurigæ, and was plainly visible to the naked eye, but was never observed visually.

A temporary star, appropriately designated "the new star of the new century," blazed out in Perseus on the night of February 21, 1901. It was discovered independently by several observers: on February 21, by Borisiak, a student at Kiev, in Russia; on the following morning, by Anderson in Edinburgh; and on the next evening, by Gore at Dublin, Nordvig in Denmark, Grimmler at Erlangen, and other observers. When first seen by Anderson, it was

equal to Algol, of the second magnitude. A photograph by Williams at Brighton showed that it must have been fainter than the twelfth magnitude on February 20. On the evening of February 23 the star was brighter than Capella, and was then the brightest star in the northern hemisphere. On February 25 it fell to the first magnitude; on March 1 to the second, and on March 6 to the third. During the spring and summer the light fluctuated considerably, but in September and October faded to the 6·7 magnitude. In March 1902 it was of the eighth magnitude, and in July 1903 of the twelfth.

The spectrum of Nova Persei was found by Pickering to be of the Orion type on February 22 and 23. On February 24 the spectrum had become one of the bright and dark lines, and the hydrogen lines indicated a velocity of 700 to 1000 miles a second. Measures of the sodium and calcium lines, by Campbell and others, indicated a velocity of only three miles a second, so that the displacements of the hydrogen lines may have been due to an outburst of hydrogen in the star. The spectrum was carefully studied during the spring and summer by Pickering, Lockyer, Huggins, Vogel, and others. On June 25 Pickering reported that the spectrum was

slowly changing into that of a gaseous nebula. In August and September 1901 the nebular spectrum became more apparent.

In August 1901 Wolf at Heidelberg discovered a faint trace of nebula near the nova. On September 20 this nebula was photographed by *George Ritchey* at the Yerkes Observatory, and was seen to be of a spiral form. This was confirmed by Perrine, who also found, from plates taken in November, that the nebula was moving at the rate of eleven minutes of arc a year. This extraordinary velocity was exceedingly puzzling to astronomers, and at length Kapteyn suggested that the nebula shone only by reflected light from the new star, and that the apparent motion was an illusion caused by the flare of the explosion travelling out from the nova.

On March 16, 1903, *Herbert Hall Turner* (born 1861), Professor of Astronomy at Oxford, discovered a new star of the seventh magnitude in the constellation Gemini, from an examination of photographic plates. Photographs taken at Harvard showed that on March 1 it must have been fainter than the twelfth magnitude, while five days later it was of the fifth. In August 1903 Pickering found its spectrum nebular. In August 1905 another small nova was found by

Mrs Fleming on the Harvard photographs, situated in Aquila.

Many theories have been advanced to account for temporary stars. Flammarion has shown that a body surrounded by a hydrogen atmosphere, on grazing a dark body enveloped in oxygen, would produce a tremendous explosion. In 1892 Huggins suggested that the outburst of Nova Aurigæ was due to the near approach of two bodies with large velocities, disturbances of a tidal nature resulting and producing enormous outbursts. Vogel suggested that the new star was due to the encounter of a dark star with a worn-out system of planets; while Lockyer believes all new stars to be due to the collision of swarms of meteors. Perhaps the most probable theory is that of Seeliger, which attributes these outbursts to the movement of a dark body through nebulous matter, which is extensively diffused throughout space. This theory explains the changes in the spectra as well as the revivals of brightness which characterised Nova Aurigæ and the fluctations of Nova Persei. In a paper read to the Royal Society of Edinburgh in November 1904, the German astronomer, *Jacobus Halm*, of the Royal Observatory, Edinburgh, extended and developed Seeliger's theory, showing also that the necessary

consequence of such an encounter as the theory assumes is the formation of an atmosphere of incandescent gases, followed by that of a revolving ring of nebulous matter. In the hands of Halm, therefore, Seeliger's theory leads to the nebular hypothesis as advanced by Laplace and Herschel.

CHAPTER XI.

STELLAR SYSTEMS AND NEBULÆ.

THE study of double stars, commenced by Herschel, was taken up after his death by several of the foremost astronomers, and has since been pursued by quite a number of observers and computers. Herschel's immediate successor in the study of double stars was his son, who ranks only second to his father as a student of stellar systems. Born at Slough on March 7, 1792, John Frederick William Herschel passed his childhood "within the shadow of the great telescope." Although his early life was spent with his father and aunt, astronomy does not appear to have taken up his attention as a boy. Chemistry, however, always interested him, and, as his aunt recorded, even while a child he was fond of making experiments. He was educated at Hitcham, and afterwards at Eton. He was delicate, however, so his mother removed him from school, and he was

trained at Slough by Mr Rogers, a Scottish mathematician. At the age of seventeen Herschel entered the University of Cambridge, and Caroline Herschel, who was exceedingly proud of him, recorded in her memoirs that he gained all the first prizes without exception. He left the University in 1813.

John Herschel did not turn his attention to astronomy until he had attained the age of twenty-four. In a letter to a friend, September 10, 1816, he said, "I am going, under my father's directions, to take up star-gazing." It was only reverence for his father that made him turn to astronomy, and he gave up the science he loved most—chemistry. But his unselfishness received its reward. In 1820 John Herschel constructed his first reflector under his father's guidance. Four years previously he had begun to observe double stars, which had been for long studied by his father, who discovered their revolutions. These observations were continued from 1821 to 1823 at the Observatory of Sir *James South* (1786-1867). John Herschel and South measured 380 of the elder Herschel's double stars. These investigations gained for Herschel and South the Lalande Prize of the French Academy and the Gold Medal of the Royal Astronomical Society.

When his mother died Sir John Herschel decided to sail to the Cape of Good Hope to make an investigation of the stars of the southern hemisphere, which until then had been much neglected. He was offered a free passage in a ship of war, but declined. In November 1833 he left England, taking with him his great telescopes. In two months he arrived at Cape Town, and erected his astronomical instruments at Feldhausen, a short distance off. In October 1835 he informed his aunt that he had almost completed his survey of the southern hemisphere. During his "sweeps" of the heavens he discovered 1202 double stars, and 1708 nebulæ and star-clusters. In 1838 he returned to England, and devoted the remainder of his life to the publication of his results, as well as to other branches of science. He died at Collingwood, in Kent, on May 11, 1871, at the age of seventy-nine.

John Herschel's favourite objects of study were double stars, of which he discovered 3347 in the northern hemisphere, and 2102 in the southern. He also computed several stellar orbits; but the first calculation of a stellar orbit was made by the French astronomer *Felix Savary* (1797-1841), who computed the orbit of ξ Ursæ Majoris, and found the period to be

about sixty years. Contemporary with John Herschel was his great rival in double-star astronomy, Friedrich Georg Wilhelm Struve. Born at Altona in 1793, Struve took his degree in 1811 at the Russian University of Dorpat. In 1813 he became director of the Dorpat Observatory, and was in 1839 promoted to Pulkowa, as director of the great Observatory there, remaining at its head until within three years of his death, on November 23, 1864. Struve's first recorded observation was on the double star Castor. In 1819 he commenced to measure the position-angles of double stars, of which he published a catalogue of 795. In 1825 he commenced a review of the heavens down to fifteen degrees south, and thus discovered 2200 previously unknown objects. The results were published in Struve's 'Mensuræ Merometricæ,' which appeared in 1836, giving the places, distances, colours, position-angles, and relative brilliance of 3112 double and multiple stars.

Struve's successor in this branch of astronomy was his son, Otto Wilhelm von Struve, born in 1819 at Dorpat, who became in 1837 assistant to his father, and in 1861 succeeded him as director of the Pulkowa Observatory. In 1890 he retired from this post, settling in Germany,

at Carlsruhe, where, on April 14, 1905, he died in his eighty-sixth year. Otto Struve detected 500 double stars, among them γ Andromedæ, discovered in 1842, and δ Equulei, discovered in 1852, within a period of between five and eleven years.

Various other astronomers have devoted themselves to the observation of double stars, among them *Ercole Dembowski* (1815-1881), of Milan; *Karl Hermann Struve* (born 1854), son of Otto Struve; *William Doberck* (born 1845); *William J. Hussey* (born 1864), now director of the Detroit Observatory; Camille Flammarion; N. C. Dunér; G. V. Schiaparelli; *Thomas Jefferson Jackson See* (born 1866). But the greatest living *discoverer* is *Sherburne Wesley Burnham* (born 1838), now employed at the Yerkes Observatory, in Wisconsin. Born in 1838 at Thetford, Vermont, he commenced his career as a shorthand reporter, studying astronomy in his leisure hours. With a small 6-inch refractor, mounted in a home-made observatory, Burnham commenced in 1871 his discoveries of double stars, which soon attracted the attention of noted astronomers, who permitted him to use larger telescopes, with which he continued his researches. His first official appointment was in 1888, when he became

chief assistant at the Lick Observatory, which position he resigned in 1892. Some years later he became astronomer in the Yerkes Observatory. Altogether he has discovered 1308 double stars, with telescopes ranging from a 6-inch refractor to the gigantic 40-inch of the Yerkes Observatory.

The computation of double-star orbits has been undertaken by various astronomers, among them Mädler, Klinkerfues, Dunér, Flammarion, Seeliger, See, Gore, Burnham, *Robert Grant Aitken* (born 1864) of the Lick Observatory, and *Giovanni Celoria* (born 1842), who was, from 1866 to 1900, assistant in the Brera Observatory of Milan, and since 1900 director of that institution. On June 9, 1890, Gore presented to the Royal Irish Academy a catalogue of computed binaries containing reference to fifty-nine stars.

In 1844 Bessel discovered a remarkable irregularity in the proper motion of Sirius. He ascribed this to the gravitational influence of some obscure body, probably a large satellite. In 1857 Peters calculated an orbit for the supposed satellite with a period of 50 years. In 1861 an orbit was computed by *Truman Henry Safford* (1836-1901), which indicated the position of the satellite. Close to this position it was accidentally discovered by *Alvan Clark*

(1832-1897), the famous American optician. The period of the star seems to be about 50 years. In 1844 Bessel noticed irregularities in the proper motion of Procyon, and put forward the idea of a disturbing satellite, as in the case of Sirius. This was confirmed by Mädler, and in 1874 an orbit was computed by Auwers, who found a period of 40 years. In 1896 the satellite was found by Schaeberle with the 36-inch refractor of the Lick Observatory. A period of 40 years was found by See, in agreement with the hypothetical orbit.

In putting forward these theories as to invisible stellar satellites, Bessel remarked that "light is no real property of mass," and that the existence of countless visible stars is nothing against the existence of countless invisible and dark ones. In this he laid the foundation of the branch of science termed by Mädler the "Astronomy of the invisible." In recent years the astronomy of the invisible has become a recognised branch of astronomical research, through the application and interpretation of Doppler's principle in spectroscopic observations. In the course of photographing the stellar spectra for the Draper Catalogue, E. C. Pickering photographed the spectrum of Mizar (ζ Ursæ Majoris) in 1887 and again in 1889. On

some of these photographs the line K was seen double, while on others it was seen under its normal aspect. This doubling of the lines indicated that the star which we see as single is in reality composed of two bodies in revolution round their centre of gravity, so close together that even the largest telescopes cannot divide them. Pickering assigned a period of 104 days, but in 1901 Vogel diminished this to 20 days. In the same year the star β Aurigæ was similarly found to be double; and in 1890 Vogel, from photographs taken at Potsdam, independently inaugurated the discovery of spectroscopic binaries. In the spectrum of Spica he discovered the spectral lines to be, not doubled, but periodically displaced, indicating the existence of a dark or nearly dark companion, both stars revolving round their centre of gravity. Spica was seen to belong to the same class as Algol, only that in the case of Algol the plane of the satellite's orbit passes through the Earth and eclipses the star, while in the case of Spica the orbit is inclined, and the star is constant in light.

The line of research commenced by Vogel and Pickering was soon followed up by these investigators, as well as by Bélopolsky at Pulkowa, Campbell at the Lick Observatory, Slipher at

the Lowell Observatory, and by *Edwin Brant Frost* (born 1866), now director of the Yerkes Observatory, and his assistant, *Walter Adams.* In 1894 Bélopolsky discovered the duplicity of several variable stars, and in 1896 that of Castor, in Gemini. Late in 1896 Campbell undertook a systematic investigation of radial motions, and has since discovered about sixty spectroscopic binaries,—among them, in 1899, the Pole Star, and in 1900 Capella. The latter discovery was made independently by *Hugh Frank Newall* (born 1857) at Cambridge, in England. It was found by Campbell that the revolution of the stars round their centre of gravity is performed in 104 days; and it soon became apparent that, owing to the large size of the orbit, the duplicity of Capella might be observed telescopically. At Greenwich the star was seen to be elongated, but at the Lick Observatory it was seen persistently single.

Campbell finds that of 285 stars observed by him, more than one in nine is a spectroscopic binary. He concludes that at least one star in five or six will be found to be spectroscopically double, and considers that "the proven existence of so large a number of stellar systems, differing so widely in structure from the Solar System, gives rise to a suspicion at least that our

system is not of the prevailing type of stellar systems."

The study of triple and multiple stars is of deep interest, but the orbits of these objects cannot be said to be fully investigated by any means. The first application of the problem of three bodies to stellar astronomy was made by Seeliger in 1889. His researches, relating to the famous star, ζ Cancri, disclosed the existence of three stars revolving round a dark body, apparently the most massive in the system. The system of ζ Cancri, at least, seems to be modelled on the Ptolemaic design.

In the study of star-clusters and nebulæ, as in the investigation of double stars, Herschel's successor was his son. His observations, both in England and at the Cape of Good Hope, resulted in a large number of new discoveries, and the results of his studies in this direction were published in 1864 in his catalogue of all known clusters and nebulæ, amounting to 5079. This catalogue was enlarged and revised in 1888 by *John Louis Emil Dreyer* (born 1852), a Danish astronomer, but director of the Observatory at Armagh, in Ireland; and the same observer published from 1888 to 1894 a supplementary list, bringing the number of known clusters and nebulæ to about 10,000.

In the early part of his career, John Herschel held firmly to the views of his father of the difference between star-clusters and nebulæ, considering the latter to be composed of "shining fluid." But he fell off from this view with the resolution into stars of many irresolvable nebulæ. In 1845 *William Parsons*, third *Earl of Rosse* (1800-1867), erected at Birr Castle, in Ireland, his great 6-foot reflector, which still surpasses all other telescopes in point of size. With this instrument Lord Rosse believed himself to have resolved the Crab nebula in Taurus and the Nebula in Orion, which was also said to have been resolved by Bond with the 15-inch refractor at Harvard; and in 1854 Olmsted declared the "resolution" of these nebulæ to be the signal for the renunciation of Herschel's nebular theory. Most astronomers fell in with the view that all the nebulæ were distant clusters, which would eventually be resolved into stars, although it is only right to state that the Scottish astronomer, *John Pringle Nichol* (1804-1859), and some other investigators, held to the theory of Herschel.

The solution of the great problem was in 1864, when on August 29 of that year Huggins turned his spectroscope on a bright planetary nebula in Draco. To his amazement the spectrum was one of bright lines, proving conclusively that the

nebula was not a star-cluster, but a mass of glowing gas,—hydrogen, and some other unknown substance, now named "nebulium." By 1868 Huggins had observed the spectra of seventy nebulæ. Of these one-third proved to be gaseous, among them the great Orion nebula which Lord Rosse was believed to have resolved into stars. In the spectrum of the latter, the "chief nebular line" was at first ascribed by Huggins to nitrogen, but this was a mistake. Later, it was believed by Lockyer to coincide with the fluting of magnesium, but this was disproved by Huggins in 1889-90, and by Keeler in 1890-91. The great nebula in Andromeda and the great spiral in Canes Venatici were found by Huggins to display a continuous spectrum, and a similar discovery was made in regard to the cluster M 13 in Hercules, and other star-clusters. In the case of the nebulæ, it is not believed that the continuous spectrum is due to the existence of sun-like bodies, as a gas under pressure would give a continuous spectrum.

The Orion nebula has been more thoroughly studied than any other object of its class. The application of photography to spectroscopy has done much to further the study of the lines in the nebular spectrum. In 1886 Copeland de-

tected in the spectrum of the Orion nebula the yellow ray of helium. On February 13, 1890, Scheiner announced an important discovery, namely, the possession by both the nebula and the stars in Orion—with the exception of Betelgeux—of a line, which appeared bright in the nebular spectra and dark in the stellar. This line was identified by Vogel, Lockyer, and others with that of helium.

Nebular photography was inaugurated in 1880 by Draper, who obtained a remarkably good representation of the Orion nebula in that year. His work in this direction, cut short by his death in 1882, was taken up by Janssen at Meudon, and by Common in England, who obtained, in 1883, several excellent photographs. Later photographs have shown the Orion nebula to be much more extended than visual observations would lead one to expect. A photograph secured in 1890 by W. H. Pickering revealed the nebulous matter in Orion in its true form, that of a gigantic spiral, starting from near Bellatrix, sweeping past κ Orionis and Rigel to η, and joining with the great nebula surrounding θ; the entire constellation being thus shown to be enwrapped in nebulous haze.

In 1885 nebular photography was commenced by *Isaac Roberts* (1829 - 1904), the English

amateur astronomer, who secured admirable representations of clusters and nebulæ. He published, in 1893 and 1900, two volumes of collected photographs of clusters and nebulæ. This monumental work was thus referred to by Dr *William James Lockyer*: "Dr Roberts has not only nobly enriched astronomical science, but has raised a monument to himself which will last as long as astronomy has any interest for mankind."

Perhaps the most remarkable revelation made by photography in this branch of research has been the discovery of the nebulæ in the Pleiades. In 1859 Tempel observed at Florence an elliptical nebula south of the star Merope. On November 16, 1885, the brothers Henry obtained at Paris a photograph of the Pleiades, revealing the existence of a small spiral nebula. This was confirmed by visual observations, and particularly by the photographs of Roberts, which also showed the entire cluster to be nebulous, and that "the nebulosity extends in streamers and fleecy masses, till it seems almost to fill the spaces between the stars, and to extend far beyond them." In 1888 a further advance was made by the brothers Henry, who found seven stars to be strung on a nebulous streak.

Since 1890 nebular photography has been pursued by Max Wolf in Germany, and by E. E. Barnard and J. E. Keeler in America. Wolf's photographs of the constellation Cygnus brought out the close connection between the stars and the extensively diffused nebulosities discovered by him. In 1901 Wolf discovered a "nebelhaufen" or cluster of nebulæ, and in 1902 published a catalogue of 1528 nebulæ round the pole of the Galaxy, showing them to be systematically distributed. Keeler made his memorable observations with the great 36-inch reflecting telescope, which was constructed in England many years ago by Common. It afterwards passed into the hands of Mr Crossley of Halifax, who presented it to the Lick Observatory. With this great instrument Keeler commenced to take photographs of the heavens. On one occasion he photographed a well-known nebula, and on developing the plate was surprised to find seven new nebulæ besides that which he had photographed. On another occasion he exposed a plate to a nebula in Pegasus. He was amazed to find altogether twenty-one nebulæ included in the photograph. To give another instance, a plate directed to the constellation Andromeda contained no fewer than thirty-two nebulous objects.

This has given an enormous extension to our knowledge of the nebulæ. But even this is not all. Keeler found on his plates numerous points of light which seem to be also nebulæ, either too small or too remote to appear as such. Apparently, however, they are not stars. Keeler's work convinced him that, on a modest estimate, there must be at least *one hundred and twenty thousand* new nebulæ within reach of the Crossley reflector. Half of these, he announced, were probably spiral. An idea of the vast importance of Keeler's work may be gained if we reflect that the observations of all the earlier astronomers resulted in the discovery of six thousand nebulæ. The investigations of Keeler, in all probability, were the means of adding 120,000 more.

Many observations have been made on nebulæ, for the purpose of ascertaining their proper motions—but without success. Measurements were made by D'Arrest in 1857 and by Burnham in 1891, but none of these revealed any motion of the nebulæ across the line of sight. Even the new spectroscopic method of determining motions in the line of sight, in the hands of Huggins, failed in the case of the nebulæ. With the great Lick refractor at his disposal, Keeler attacked the subject in 1890, and

measured the radial velocities of ten nebulæ. He found that the well-known planetary nebula in Draco was moving towards the Solar System at the rate of 40 miles a second; for the Orion nebula he found a motion of recession of 11 miles a second; but probably this belongs chiefly to the movement of the Solar System in the opposite direction.

Unfortunately Keeler did not live to carry on his investigations in nebular astronomy. His early death brought to an abrupt end these fruitful investigations. Appointed director of the Lick Observatory in 1898, he died suddenly at San Francisco on August 12, 1900, at the early age of forty-two.

CHAPTER XII.

STELLAR DISTRIBUTION AND THE STRUCTURE OF THE UNIVERSE.

After the death of Herschel there was little done in the direction of furthering our knowledge of stellar distribution, or the construction of the heavens. Here, as elsewhere, Herschel's immediate successor was his son, whose star-gauges, both in England and in South Africa, were a worthy sequel to those of his father; but John Herschel, in his books on astronomy, reproduced his father's disc-theory, unaware that the elder Herschel had himself abandoned it. The work of the younger Herschel was entirely supplementary to that of his father.

To Wilhelm Struve belongs the credit of showing the disc-theory to be untenable, and of demonstrating that Herschel had abandoned it. This he was able to do after a perusal of Herschel's papers, presented to him by John Herschel. Having demonstrated this, he under-

took a series of investigations which resulted in his famous theory of the Universe. This was published in his work 'Études d'Astronomie Stellaire,' which was published in 1847. His researches were based on the star-catalogues of Bessel, Piazzi, and others; and dealing with 52,199 stars, he discussed the number of stars in each zone of Right Ascension. He found, in the words of Mr Gore, "that the numbers increase from hour i to hour vi, where they attain a maximum. They then diminish to a minimum at hour xiii, and rise to another but smaller maximum at hour xviii, again decreasing to a second minimum at hour xxii. As the hours vi and xviii are those crossed by the Milky Way, the result is very significant." He concluded the Galaxy to be produced by a collection of irregularly-condensed clusters, the stars condensed in parallel planes. Next, he considered the Universe as perhaps infinitely extended in the direction of the Galaxy, and accordingly he put forward the idea that the light from the fainter and more distant stars was extinguished in its passage through the ether of space, which he regarded as imperfectly transparent. The theory, as Struve propounded it, was disposed of by Sir John Herschel, who remarked that we were not permitted to

believe that at one part of the sky our view was limited by extinction, while at another a clear view right through the Galaxy could be had; and by *Robert Grant* (1814-1892), director of the Glasgow Observatory, who showed that, were the theory true, the Galaxy should present a uniform appearance throughout its course. On the whole, Struve's theory was no improvement on Herschel's; for, as Encke pointed out, Struve's theory was built on five assumptions, all of which were questionable.

At the time of Struve's investigation Mädler, at Dorpat, was engaged in an attempt to solve the question of the construction of the heavens by quite another method, that of stellar proper motion. He determined to investigate the subject of proper motion in order to discover the central body of the Milky Way. If such a centre existed, however, the motions near it would be somewhat different from those in the Solar System. In our Solar System the planets nearest the Sun move swiftest, owing to the strength of the force of gravitation. In the Sidereal System, on the other hand, the movements at the centre, as Mädler pointed out, would be slowest. As there would be no very large preponderating body, the mutual attractions of the different stars would cause the bodies

at the boundaries of the Universe to move faster than those at the centre, the central sun—the object of Mädler's search—being in a state of rest relative to the Sidereal System. Mädler accordingly began to search the heavens for a region of sluggish proper motions.

In the constellation Taurus, Mädler noticed that the proper motions of the stars were very slow. The idea occurred to him that the bright red star Aldebaran might be the central sun, but its very large proper motion was obviously against this inference. Star after star was now subjected by Mädler to the most careful scrutiny. At length, after a laborious investigation, he announced that the star which fulfilled the conditions of a central body was Alcyone, the brightest of the Pleiades, a group possessed of no proper motion except that due to the sun's drift in the opposite direction. In 1846 Mädler published his hypothesis in his elaborate work, 'The Central Sun.' He announced that his observations had led him to the conclusion that Alcyone occupied the centre of gravity of the Sidereal System, and was the point round which the stars of the Galaxy were all revolving. His profound imagination, however, did not stop here. This speculation led him to the sublime thought that the centre of the Universe was

the Abode of the Creator. In 1847 Struve rejected Mädler's theory as "much too hazardous," and this has been the general opinion of astronomers. Mädler's theory is now regarded as quite untenable.

Herschel's earlier idea that the nebulæ were external galaxies was long held by the majority of astronomers, in preference to his later and more advanced ideas. The supposed resolution of the nebulæ by Lord Rosse's telescope gave support to this external galaxy theory. It was clearly shown, however, by *William Whewell* (1794-1866) in 1853, and by *Herbert Spencer* (1820-1903) in 1858, that the systematic distribution of the nebulæ in regard to the stars precluded the possibility of their being external galaxies. This was confirmed by the spectroscopic discovery of the gaseous nature of some of the nebulæ, and by the later researches of R. A. Proctor. Not only did Proctor make fresh discoveries, but it fell to him to clear away the erroneous ideas regarding the construction of the heavens, and to put the study on a new basis. In 1870 Proctor plotted on a single chart all the stars, to the number of 324,198, contained in Argelander's 'Durchmusterung' charts. This work gave the death-blow to the "disc-theory." In his own words, "In the very regions where

the Herschelian gauges showed the minutest telescopic stars to be most crowded, my chart of 324,198 stars shows the stars of the higher orders (down to the eleventh magnitude) to be so crowded, that by their mere aggregation within the mass they show the Milky Way with all its streams and clusterings. It is utterly impossible that excessively remote stars could seem to be clustered exactly where relatively near stars were richly spread."

Proctor showed also that in all probability the stars composing the nebulous light of the Galaxy are much smaller than the brighter stars, and not at such a great distance as their faintness would lead us to suppose,—a conclusion confirmed by the work of Celoria. Proctor was not so fortunate in theorising as in direct investigation. He thought that the Magellanic clouds were probably external galaxies; and further, he put forward the idea that the Milky Way is a spiral, the gaps and coal-sacks being due to loops in the stream, but neither of these ideas has found favour with astronomers. But the chief work accomplished by Proctor was a revision of our knowledge of the Universe, which he thus describes: "Within one and the same region coexist stars of many orders of real magnitude, the greatest being thousands of times larger

than the least. All the nebulæ hitherto discovered, whether gaseous and stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the Sidereal System."

Proctor's discovery of the excess of bright stars on the Galaxy was confirmed by *Jean Charles Houzeau* (1820-1888), director of the Brussels Observatory. Some time later J. E. Gore carefully examined the positions of all the brighter stars in the northern and southern hemisphere. Following this, he made an enumeration of the stars in the atlas of Heis and in the charts constructed by Harding; the outcome of the investigation being to show that stars of each individual magnitude taken separately tend to aggregate on the Galaxy, the aggregation being noticed even in first-magnitude stars. Gore further pointed out many cases of close connection between the lucid stars and the galactic light. A similar investigation was undertaken by Schiaparelli in 1889. Schiaparelli, basing his work on the catalogue of Gould and the photometric measures of Pickering, constructed a series of planispheres which demonstrated the crowding of the lucid stars towards the plane of the Galaxy. These investigations were still further continued by Simon Newcomb, who demonstrated that "the darker regions of the Galaxy are only

slightly richer in stars visible to the naked eye than other parts of the heavens, while the bright areas are between 60 and 100 per cent richer than the dark areas." The Dutch astronomer, *Charles Easton*, finds a connection between the distribution of ninth-magnitude stars and the luminous and obscure spots in the Galaxy.

It was noticed by Gould, from observations made at Cordova, that "a belt or stream of bright stars appears to girdle the heavens very nearly in a great circle which intersects the Milky Way." According to Gould, the belt includes Orion, Canis Major, Argo, Crux, Centaurus, Lupus, and Scorpio in the southern hemisphere, and Taurus, Perseus, Cassiopeia, Cepheus, Cygnus, and Lyra in the northern. This was interpreted by Celoria as indicating the existence of two galactic rings, but Gould considered the zone of bright stars to form with the Sun a subordinate cluster of about five hundred stars within the Galaxy.

Perhaps the most elaborate investigations on the structure of the Universe have been those of Kapteyn, commenced in 1891. In that year he demonstrated that stars are bluer and more easily photographed in the Galaxy than elsewhere, a discovery independently made by Gill at the Cape, and Pickering at Har-

vard. In 1893 Kapteyn announced his conclusions, derived from a novel method of studying the distance of the stars from their proper motions. In order to reach a definite idea of the distances of the stars, he made use of the component of the proper motion, measured at right angles to a great circle of the sphere which passes through a given star and the apex of the solar motion. He found that stars of the first spectral type have smaller proper motions than those of the second, indicating that stars of the second type are on the average nearer to the Solar System than those of the first, the near vicinity containing almost exclusively second-type stars. Kapteyn concluded that the group of second-type stars formed one system, named the solar cluster, which he considered to be roughly spherical in shape. In 1902 he abandoned this idea, retaining, however, his opinions as to the relative distances of the different types. That the second-type stars are nearer to the Sun than the first is, he remarked in a letter to the writer, incontrovertible.

In the investigation of the motions in, and extent of, the Universe, the name of Simon Newcomb stands out pre-eminently. Born in 1835 at Wallace, in Nova Scotia, he went to

the States in 1853. In 1862 he received an appointment at Washington Observatory, and he retained an official position until 1897. Throughout his scientific career he has been specially attracted by the question of the construction of the heavens, which he fully discussed in his book on 'The Stars' in 1901. Newcomb's investigations have shown that some of the stars are not permanent members of the Sidereal System, among them the swiftly-moving 1830 Groombridge. He has shown that the Stellar Universe does not possess that form of stability which is seen in the Solar System. Newcomb considers the Universe to be limited in extent, as opposed to the opinions of Struve and others, who believed it to be infinite. He has brought clearly before his readers a calculation, based on the known law that there are three times as many stars of any given magnitude as of that immediately brighter, the increase of number compensating for the decrease of brilliance. Were the Universe infinitely extended, the whole heavens would shine with the brilliance of the Sun. Newcomb, therefore, concludes that "that collection of stars which we call the Universe is limited in extent."

Positive evidence that this is the case was obtained by Giovanni Celoria, now director of

the Milan Observatory, in the course of a series of star-gauges at the north galactic pole. Using a small refractor, showing stars barely to the eleventh magnitude, he found he could see exactly the same number of stars as Herschel's large reflector, indicating that increase of optical power will not increase the number of stars visible in that direction. Celoria's observation can only be explained on the assumption that the Universe is limited in extent, as otherwise Herschel's telescope should have shown more stars than Celoria's, even granting an extinction of light,—a theory which Newcomb, Schiaparelli, and others have shown to be quite untenable. That the Universe is limited in extent is about all that is known for certain, although even this has been called in question, notably by E. W. Maunder and H. H. Turner. The problem of the construction of the heavens is by no means solved, although several more or less probable theories have been advanced.

A series of investigations on stellar distribution, from 1884 to 1898, led Hugo Seeliger, director of the Munich Observatory, to some remarkable deductions. He believes the Universe to be flattened at the galactic poles. The Galaxy is the zone of stellar condensation, and he concludes the distance of the Solar System

from the inner border of the zone to be 500 times the distance of Sirius, while the external border is 1100 times that distance. The Universe is finite in extent, its limits being about 9000 light years from the Solar System. In Seeliger's opinion the extinction of light may come into play beyond our Universe, and prevent us seeing other collections of stars.

The question of external universes is purely a hypothetical one, although there is undoubtedly much to be said in its favour. These universes have never been seen, and we can only speculate as to their existence. The last word on the subject is by Gore, in 1893, in his elaborate work, 'The Visible Universe.' He regards the Solar System as a system of the first order, and the Galaxy and its fellow-universes of the second. He makes a calculation of the possible distance of an external universe of his second order. He assumes the distance of the nearest universe from our Galaxy as proportional to that separating the Sun from α Centauri, and reaches the amazing conclusion that the distance of the nearest Galaxy is no less than 520,149,600,000,000,000,000 miles, — a distance which light, with its inconceivable velocity of 186,000 miles a second, would take almost ninety millions of years to traverse.

These calculations absolutely overwhelm the mind, which is unable to comprehend such vast distances. Our universe is indeed, as Flammarion expresses it, a point in the infinite. The calculations of J. E. Gore represent our highest scientific conception of the universe. He sums up his investigations with the following words: "Although we must consider the number of *visible* stars as strictly finite, the numbers of stars and systems really existing, but invisible to us, may be practically infinite. Could we speed our flight through space on angel wings beyond the confines of our limited universe to a distance so great that the interval which separates us from the remotest fixed star might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision? Systems of a higher order might there be unfolded to our view, compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore,—systems perhaps stretching out to infinity before us, and reaching at last the glorious 'mansions' of the Almighty, the Throne of the Eternal."

CHAPTER XIII.

CELESTIAL EVOLUTION.

In the second chapter we outlined the nebular hypothesis as propounded by Herschel. Some time earlier the French mathematician, Laplace, had put forward his theory of the evolution of the Solar System. *Pierre Simon Laplace* was born at Beaumont-en-Auge, near Honfleur, in 1749, and was educated in the Military School of his native town. In 1767 he became Assistant Professor of Mathematics at Beaumont, and some years later at the Military School in Paris, which position he retained for many years. Member of the Institute and Minister of the Interior under Napoleon, he was created a Marquis by Louis XVIII., and died at Arcuile on March 5, 1827.

In the last chapter of his popular work, the 'Système du Monde,' Laplace put forward his nebular theory "with that distrust which everything ought to inspire that is not the result of

observation or calculation." Laplace noticed that in the Solar System all the planets revolved round the Sun in the same direction, from west to east, and that the satellites of the planets obeyed the same law. He also observed that the Sun, Moon, and planets rotated on their axes in the same direction as they revolved round the Sun; also that the planets moved round the Sun, and the satellites round their primaries, in almost the same plane as the Earth's orbit, the plane of the ecliptic. It was evident that these remarkable congruities were not the result of chance, and accordingly Laplace expressed his belief that the Solar System originated from a great nebula, which in condensing detached various rings in the process of rotation. These rings condensed into the various planets and their satellites.

Laplace's theory was powerfully supported by Herschel's observations of the various nebulæ in the heavens. But, with the supposed resolution of the various nebulæ after the erection of the Rosse reflector in 1845, the evidence in favour of the nebular theory seemed to be greatly reduced. In 1864, however, the discovery of the gaseous nebulæ, by means of the spectroscope, gave further support to the theory. Powerful aid was lent to the nebular hypoth-

esis by the famous German physicist, *Hermann Ludwig Ferdinand von Helmholtz* (1821-1894), in 1854, in his theory of the maintenance of the Sun's heat. Many theories had been already advanced to account for this. After the discovery of the conservation of energy, *Julius Robert Mayer*, one of the discoverers, put forward the theory that the Solar heat was sustained by the inflow of meteorites from space, and this idea was developed in 1854 by Sir *William Thomson*, now *Lord Kelvin* (born 1824), but it was soon apparent that the supply of meteors required to sustain the Solar heat was such as would have increased the mass of the Sun very considerably. Accordingly the hypothesis was partially abandoned, and was succeeded by that of Helmholtz, who pointed out that the radiation of the Sun's heat was the result of its contraction through cooling. The rate was then estimated at 380 feet yearly, or a second of arc in 6000 years. This theory was at once generally accepted. It assumes the Sun to be still contracting, and therefore, on going backwards in imagination, we reach a period when the Sun must have been much larger than now, and, in fact, extended beyond the orbit of Neptune.

Several objections to Laplace's nebular theory

were urged by various investigators. Among these was the retrograde motions of the satellites of Uranus and Neptune, and the extremly rapid revolution of the inner satellite of Mars. Other objections were urged by Babinet, Kirkwood, and others, and at length a sweeping reform of the nebular theory was proposed by Faye in 1884, in his work, 'Sur l'Origine du Monde.' Faye put forward the idea that all the planets interior to the orbit of Uranus were formed inside the solar nebula, while Uranus and Neptune came into existence after the development of the Sun was far advanced. But the objections to Faye's theory are formidable, and the hypothesis has not been accepted.

A popular exposition of the nebular theory was given in 1901 in Ball's work on 'The Earth's Beginning.' He exhaustively discusses the whole question, and explains the retrograde motion of the satellites of Uranus and Neptune as due to the fact that the planes of the orbits of the satellites will eventually be brought to coincide with the ecliptic. These motions, says Ball, do not disprove the nebular theory. "They rather illustrate the fact that the great evolution which has wrought the Solar System into its present form has not finished its work: it is still in progress."

The theory that the Sun's heat was maintained by meteors, was extended by Proctor in 1870 to explain the growth of the planets through meteoric aggregation as well as nebular condensation. Certainly the theory, as developed by Proctor, accounted fairly well for the various features of the Solar System; but the highest development of the meteoritic theory is due to Lockyer, who published his views in 1890, in his work, 'The Meteoritic Hypothesis.' Lockyer claims that his views are merely extensions of Schiaparelli's ideas regarding the concentration of celestial matter. He considered the chief nebular line to be identical with the remnant of the magnesium fluting, which is conspicuous in cometic and meteoric spectra; but Huggins and Keeler, with more powerful instruments, disproved the supposed coincidence. Lockyer considers that "all self-luminous bodies in the celestial space are composed either of swarms of meteorites or of masses of meteoric vapour produced by heat. The heat is brought about by the condensation of meteor swarms, due to gravity, the vapour being finally condensed into a solid globe."

Lockyer divided the stars into seven groups, according to temperature, the order of evolution being from red stars through a division of second-

type stars to Sirian stars, regarded as the hottest stars; through a second division of solar stars to fourth-type stars. In fact, the theory aspires to give a complete explanation of all celestial phenomena, from meteors to nebulæ. Newcomb, however, considers that the objections to the theory are insuperable, and his opinion is shared by the majority of astronomers, many of whom, however, consider that there are elements of truth in the theory; but Lockyer undoubtedly carried his ideas to an extravagant extent.

Lockyer's evolutionary order of the stars is not supported by Vogel. Zöllner suggested in 1865 that yellow and red stars are simply white stars in a further stage of cooling; but Angström showed that atmospheric composition is a safer criterion of age than colour. Vogel's classification, first published in 1874, and further developed in 1895, is from the standpoint of evolution. He considers Orion stars and Sirian stars to be the youngest orbs. Solar stars are considered by Vogel to have wasted much of their store of radiation, and red stars are viewed as "effete suns, hastening rapidly down the road to final extinction." He considers stars of Secchi's fourth type to be also dying suns, both types representing alternative roads for stars of the Solar type in their decline into dark stars. This view is

supported by Dunér, and is distinctly confirmed by Hale's observations with the Yerkes telescope. Vogel's views, in fact, are generally accepted among astronomers. The nebular theory, modified by subsequent research, seems destined to hold its own against all attacks.

Distinctly supplementary to the nebular theory are the remarkable researches, commenced in 1879, by Sir *George Howard Darwin* (born 1845), son of Charles Darwin the great biologist. George Howard Darwin was born in 1845, at Downe in Kent, was educated at Cambridge, and studied for the law; but in 1873 he returned to Cambridge, where he became Plumian Professor of Astronomy in 1883. In 1879 he communicated to the Royal Society the first of his papers on tidal friction, which were summed up in his book on 'The Tides,' published in 1898. He finds that the tides act upon the Earth as a brake does upon a machine,—they tend to retard its rotation. Consequently, the day is growing longer, the Moon's orbit is becoming enlarged, and its period of revolution is being lengthened.

At present the day is about twenty-four hours long, and the month about twenty-seven days. The day, however, will be lengthened at a more rapid rate than the month, and in the remote future the day and month will both last fifty-five

of our present days. The Moon will revolve round the Earth in the same period that the Earth rotates on its axis, and the two bodies will perform their circuit round the Sun as if united by a bar.

Not only can we foresee the future of the Earth-Moon System, but we can also read the past. According to Darwin's theory, the Earth, in the remote past, was probably rotating on its axis in a very short period, between three and five hours. The Moon must then have been much nearer us than it is now, and was probably revolving round its primary in the same period that the Earth took to rotate on its axis. The two globes, then gaseous, must have been revolving almost in actual contact. Had the month been even a second shorter than the day, the Moon must inevitably have fallen back on the Earth. As it was, the condition of affairs could not endure. The condition of the Moon resembled that of an egg balanced on its point. The Moon must either recede from the Earth or fall back upon it. The solar tide here interfered, and caused the Moon to recede from its primary until it reached its present distance of 239,000 miles.

The fact that the Earth and Moon were almost in contact suggests that they were probably *in*

contact. In other words, the Moon originally formed part of the Earth, which, in consequence of its short-rotation period, and probably also owing to the interference of the solar tide, split into two portions, and the smaller of these now forms the Moon. It is likely that the matter now forming the Moon was detached from the Earth in separate particles. Just as the tides raised by the Moon tend to retard the motion of the Earth, so the Earth tides raised in the Moon have already done their work. The Moon now rotates on its axis in the same time as it revolves round the Earth. Part of the evolution of the Earth-Moon system is completed. Schiaparelli's discovery that the rotation periods of both Venus and Mercury coincide with their times of revolution is distinctly confirmatory of Darwin's theory.

In his chapter on the "Evolution of Celestial Systems" in his book on 'The Tides,' Darwin discusses the distribution of the satellites of the Solar System. He says of the evolution of a planet: "We have seen that rings should be shed from the central nucleus when the contraction of the nebula has induced a certain degree of augmentation of rotation. Now, if the rotation were retarded by some external cause, the genesis of a ring might be retarded or entirely prevented."

He then remarks that probably the formation of the Moon was retarded, and in the case of Mercury and Venus, solar tidal friction prevented satellite formation. This explains why Mercury and Venus have no satellites, the Earth only one, Mars two, while the exterior planets have each several satellites.

The theory of tidal friction was extended in 1892 to the explanation of the double stars by the American astronomer, See. See showed by mathematical calculation the effects of tidal friction in shaping the eccentric orbits of the binary stars, the course of evolution being traced from double stars, revolving almost in contact, which the spectroscope reveals, to the telescopic doubles. See's researches have done much to supplement those of Darwin, who considers that there are two types of cosmical evolution, —the Laplacian, and the "second" or lunar type.

Lowell, in his work on 'The Solar System' (1903), adds six congruities to those remarked by Laplace and his successors. These are, "All the satellites turn the same face to their primaries (so far as we can judge); Mercury, and probably Venus, do the same to the Sun; one law governs position and size in the Solar System and in all the satellite systems; orbital

inclinations in the satellite systems increase with distance from the primary; the outer planets show a greater tilt of axis to orbit-plane with increased distance from the Sun (so far as detectable); the inner planets show a similar relation."

The fate of the average solar star is sketched out by Vogel's classification, and by any evolutionary hypothesis which we may adopt. In the words of Lowell: "Though we cannot as yet review with the mind's eye our past, we can, to an extent, foresee our future. We can with scientific confidence look forward to a time when each of the bodies composing our Solar System shall turn an unchanging face in perpetuity to the Sun. Each will then have reached the end of its evolution set in the unchanging stare of death. Then the Sun itself will go out, becoming a cold and lifeless mass; and the Solar System will circle unseen, ghostlike, in space, awaiting only the resurrection of another cosmic catastrophe."

As to what this cosmic catastrophe will be, science gives no definite idea; nor can astronomers say with certainty whether the Universe will come to an end by the extinction of its luminaries, or whether the suns and planets will be brought back to luminosity again; but the human mind shrinks from the idea of a

dead Universe. At this point science has said its last word, and must give place to religion. In our day we may repeat with deeper meaning the words of the Scottish astronomer, Thomas Dick: "Here imagination must drop its wing, since it can penetrate no further into the dominions of Him who sits on the Throne of Immensity. Overwhelmed with a view of the magnificence of the Universe, and of the perfections of its Almighty Author, we can only fall prostrate in deep humility and exclaim, 'Great and marvellous are Thy works, Lord God Almighty.'"

INDEX.

Absolute parallax, 158.
Adams, J. C., 78, 116, 117, 118, 119, 120, 140.
Adams, W., 205.
Aerolites, 147, 148, 149.
Airy, Sir G. B., 27, 104, 117, 120.
Aitken, R. G., 202.
Alcyone (η Tauri), 217.
Aldebaran (α Tauri), 151, 166, 170, 172.
Algol (β Persei), 178, 182, 183, 184, 193, 204.
Al-Sufi, 180, 183.
Altair (α Aquilæ), 170.
Anderson, T. D., 191, 192.
Andromeda nebula, 180, 208.
Andromedæ (γ), 201.
Andromedæ (Nova), 180.
Andromedid meteors, 142, 149.
Angström, A. J., 50, 51.
Antares (α Scorpii), 171.
Aquila, 195.
Aquilæ (η), 185, 186.
Arago, F. J. D., 6, 11, 31, 37, 40, 118, 120, 129.
Arcturus (α Bootis), 165, 170.
Arequipa Observatory, 75.
Argelander, F. W. A., 27, 159, 167, 178, 179, 180, 218.
Argo Navis, 221.
Argus (η), 187, 188.
Armagh Observatory, 206.
Asteroids, 19, 62, 97-102.
Astronomer-Royal of Scotland, 134, 155, 191; of England, 59, 117; of Ireland, 151, 156.
Astronomy of the invisible, 203.
Aurigæ (Nova), 191, 192, 195.
Auwers, A., 167, 188, 203.

Babinet, 230.
Baily, F., 159.
Bakhuyzen, H. G., 91.
Ball, Sir R. S., 23, 34, 108, 141, 149, 156, 158, 230.
Barnard, E. E., 19, 95, 107, 108, 110, 111, 113, 136, 191, 211.
Beer, W., 68, 69, 90.
Bellatrix (γ Orionis), 209.
Bélopolsky, A., 87, 110, 166, 185, 186, 204, 205.
Berlin Observatory, 119, 120.
Bessel, F. W., 24, 82, 116, 151, 152, 153, 154, 159, 167, 202, 203.
Betelgeux (α Orionis), 165, 171, 172, 182, 187.
Biela, W., 128.
Biela's comet, 128, 129, 142, 143, 146, 149.
Birmingham, J., 189.
Bode, J. E., 97, 98, 152.
Bode's Law, 97.
Boeddicker, O., 77.
Bond, G. P., 103, 109, 130, 136, 207.

Bond, W. C., 109, 112, 120.
'Bonn Durchmusterung,' 159, 160, 218.
Bonn Observatory, 88, 97, 160.
Böotis (ε), 30.
Borisiak, 192.
Boss, L., 168.
Bouvard, A., 115, 116.
Bradley, J., 159, 167.
Brédikhine, T. A., 105, 131, 132, 133, 134, 135.
Brewster, Sir D., 50, 101, 178.
Brinkley, J., 151.
Brünnow, F., 156.
Bruno, G., 35.
Buffon, 103.
Bunsen, R. W., 51.
Burchell, 188.
Burnham, S. W., 201, 202, 212.

Callandreau, O., 136.
Callandrelli, 151.
Cambridge Observatory, 116.
Campbell, T. (Poet), 2.
Campbell, W. W., 24, 107, 110, 166, 168, 187, 191, 193, 204, 205.
Canals of Mars, 91, 92, 93, 94, 95.
Cancri (ζ), 206.
Cancri (S), 180.
Canis Major, 188.
'Cape Durchmusterung,' 161, 162.
Cape Observatory, 155, 157.
Capella (α Aurigæ), 170, 176, 193, 205.
Carnera, L., 100.
Carpenter, J., 73.
Carrington, R. C., 45, 46, 59.
Cassini, D., 21.
Cassiopeia, 221.
Castor (α Geminorum), 30, 200, 205.
Celoria, G., 202, 218, 221, 223, 224.
Centauri (α), 155, 188, 225.
Centaurus, 221.
Cephei (δ), 178, 182, 185, 186.
Cepheus, 221.
Ceres, 19, 98, 101.
Cerulli, V., 86, 91, 94.
Chacornac, 161.
Challis, J., 116, 119, 120.
Chambers, G. F., 31.
Chandler, S. C., 88, 89, 181, 184.
Chladni, E., 138.
Chromosphere, solar, 55, 56.
Clark, A., 202.
Clerke, Miss A. M., 3, 5, 8, 12, 13, 15, 25, 26, 34, 42, 58, 75, 86, 92, 105, 109, 124, 125, 131, 132, 133, 140, 142, 169, 186, 187, 189.
Clerk-Maxwell, J., 109, 110.
Coggia's comet, 131, 132, 133.
Comet families, 135.
Comets, 24, 123-137, 141, 142, 143, 144, 146, 149, 152.
Common, A. A., 107, 209.
Copeland, R., 134, 135, 190, 208.
Cornu, A., 189.
Corona Borealis, 188.
Corona, solar, 55, 57, 64.
Coronæ (Nova), 188, 189.
Crossley, E., 211.
Crux, 221.
Cygni (61), 152, 158.
Cygni (Y), 184, 185.
Cygni (Nova), 189, 190.
Cygnus, 152, 189, 221.

Damoiseau, 78.
D'Arrest, H. L., 96, 119, 142, 212.
Dartmouth Observatory, 56.
Darwin, Sir G. H., 233, 234, 235, 236.
Dawes, W. R., 90, 117.
De la Rue, W., 52, 75.
Delaunay, C. E., 78, 79.
Dembowski, E., 201.
Deneb (α Cygni), 165.
Denning, W. F., 84, 85, 91, 95, 105, 111, 112, 144, 145, 146.
Deslandres, H., 110.
Dick, T., 85, 238.
Disc-theory, 32, 36, 38, 39, 214, 218.
Di Vico, F., 85, 86, 170.

Doberck, W., 201.
Donati, G. B., 130, 131, 169.
Donati's comet, 130, 133, 136.
Doppler, C., 57, 58.
Doppler's Principle, 58, 59, 87, 110, 165, 168, 203.
Douglass, A. E., 92, 107.
Draconis (λ), 182.
Draper, H., 136, 172, 175.
Dreyer, J. L. E., 206.
Dunecht Observatory, 157.
Dunér, N. C., 58, 59, 174, 175, 181, 184, 185, 201, 202, 233.
Dunkin, E., 27, 167.
Dunsink Observatory, 156.

Earth, 76, 97, 103, 104, 147, 148, 149, 153, 154, 156, 236.
Earth-Moon system, 234, 235.
Easton, C., 221.
Eclipses, lunar, 77.
Eclipses, solar, 56, 57, 80, 81.
Edinburgh (Royal) Observatory, 195.
Electrical repulsion theory, 126.
Elger, T. G., 74.
Elkin, W. L., 157.
Encke, J. F., 30, 61, 119, 127, 128, 216.
Encke's comet, 127, 128, 137.
Erman, 140.
Eros, 62, 101.
Ertborn, 85.
Euler, L., 88, 89.
Evolution, planetary, 228, 229, 230, 231.
Evolution, stellar, 33, 34, 231, 232.

Faye, H., 60, 129, 230.
Faye's comet, 129, 137.
Ferguson, J., 9, 178.
Flammarion, C., 87, 91, 95, 121, 147, 164, 187, 195, 201, 202, 226.
Flamsteed, J., 5.
Fleming, Mrs, 192, 195.
Forbes, G., 122.
Fraunhofer, J. 47, 48, 49, 50, 151, 153, 169.
Fraunhofer lines, 48, 49, 50, 51, 169, 172.
Frost, E. B., 205.

Galactic poles, 35, 224.
Galaxies, external, 32, 218, 225, 226.
Galaxy, or Milky Way, 32, 36-42, 186, 211, 215, 216, 217, 219, 220, 221; 224, 225.
Galileo, 44, 107.
Galle, J. G., 62, 108, 109, 119, 142.
Galloway, T., 167.
Gambart, 128.
Gauss, C. F., 27, 98, 167.
Gautier, A., 45.
Gemini, 11, 194.
Geminorum (Nova), 194.
Geminorum (ζ), 180, 182, 185.
George III., 11, 23.
Gill, Sir D., 62, 136, 155, 157, 160, 161, 221.
Glasgow Observatory, 216.
Goodricke, J., 178, 183.
Gore, J. E., 24, 38, 179, 181, 182, 183, 192, 202, 215, 220, 225, 226.
Gould, B. A., 135, 160, 163, 180, 220, 221.
Grant, R., 216.
Gravitation, law of, 29.
Greenwich Observatory, 59, 117.
Grimmler, 192.
Groombridge (1830), 156, 162, 223.
Groombridge (1618), 156.
Gruithuisen, 87.

Hale, G. E., 55, 57, 233.
Hall, A., 96, 111, 112, 156, 190.
Hall, Maxwell, 121.
Halley, E., 138.
Halley's comet, 123, 130, 152.
Halm, J., 195, 196.
Hansen, P. A., 61, 78, 79.
Hansky, A., 57.
Harding, K. L., 99, 153, 220.
Hartwig, E., 190.

Harvard Observatory, 174, 175, 191.
Hasselberg, B., 148, 190.
Heis, E., 179, 220.
Heliometer, 153, 157.
Helium stars, 174.
Helmholtz, H., 61, 229.
Hencke, K. L., 99.
Henderson, T., 154, 155.
Henry, Paul and Prosper, 100, 114, 210.
Hercules, 167.
Herculis (α), 182.
Herculis (λ), 26.
Herschel, William, 1-42, 43, 60, 63, 65, 69, 74, 77, 85, 90, 99, 103, 109, 111, 112, 115, 123, 150, 162, 167, 176, 196, 197, 207, 214, 216, 218, 224, 227.
Herschel, A., 144.
Herschel, Caroline, 6, 8, 9, 12, 13, 14, 30, 35, 127, 198.
Herschel, Sir J., 4, 17, 27, 30, 37, 50, 112, 113, 120, 130, 144, 167, 187, 188, 197, 198, 199, 200, 214, 215.
Hind, J. R., 99, 129, 135, 180, 188.
Hoek, 135.
Holden, E. S., 191.
Hough, G., 105.
Houzeau, J. C., 220.
Huggins, Lady, 172.
Huggins, Sir W., 54, 57, 74, 95, 106, 114, 131, 136, 165, 170, 171, 172, 173, 189, 190, 191, 193, 195, 207, 208, 212, 231.
Humboldt, A., 44, 139.
Hussey, W. J., 116, 201.

Innes, R., 188.
Intra-Mercurial planet, 80, 81.
Italian spectroscopists, 54, 55.

Janssen, P. J. C., 52, 53, 54, 57, 59, 112, 209.
Juno, 19, 99, 101.
Jupiter, 20, 75, 97, 101-108, 112, 114, 121, 122, 135, 144, 146.
Juvisy Observatory, 164.

Kaestner, 65, 124.
Kaiser, F., 90.
Kant, I., 34, 35, 101, 103.
Kapteyn, J. C., 27, 158, 161, 162, 168, 221, 222.
Keeler, J. E., 95, 114, 185, 208, 211, 212, 213, 231.
Kelvin, Lord, 229.
Kempf, P., 181.
Kepler, J., 5, 35, 137.
Kirchoff, G. R., 61, 169, 172.
Kirkwood, D., 140, 230.
Klein, H. J., 73.
Klinkerfues, E., 142, 202.
Konkoly, N., 175.
Küstner, F., 88.

Lalande, 23, 152.
Lambert, J. H., 34.
Lamont, J., 44.
Langley, S. P., 77.
Laplace, P. S., 20, 33, 34, 77, 109, 148, 152, 195, 227, 228, 229.
Lassell, W., 112, 115, 117, 120.
Latitude, variation of, 88, 89.
Leipzig Observatory, 173.
Leonid meteors, 139, 140, 142.
Leonis (β), 183.
Lescarbault, 80.
Le Verrier, U. J. J., 61, 80, 81, 118, 119, 120, 142, 164.
Leyden Observatory, 91.
Libræ (δ), 180.
Lick Observatory, 93, 107, 166, 168, 191, 213.
Light, extinction of, 40, 215, 216, 224, 225.
Lindsay, Lord, 157.
Linné, 71, 72.
Lockyer, Sir J. N., 52, 53, 54, 55, 58, 149, 174, 191, 193, 195, 208, 209, 231, 232.
Lockyer, W. J. S., 210.
Loewy, M., 75.
Lohrmann, W. G., 68, 71.
Lohse, W. O., 88, 105.
Loomis, 188.

Lowell, P., 83, 84, 86, 87, 91, 92, 93, 94, 122, 236, 237.
Lowell Observatory, 92, 94, 106, 114.
Lund Observatory, 59.
Lupus, 221.
Luther, R., 100.
Lyra, 221.
Lyræ (β), 178, 182, 185.
Lyrid meteors, 122.

Maclaurin, C., 9.
Maclear, Sir T., 155.
Mädler, J. H., 27, 68, 69, 71, 96, 104, 202, 203, 216, 217, 218.
Magellanic clouds, 219.
Magnetism, 44, 60.
Mars, 18, 19, 90-97, 101, 144, 236.
Maunder, E. W., 59, 60, 94, 95, 134, 145, 166, 224.
Mascari, A., 86.
Mayer, C., 164.
Mayer, J. R., 229.
Mazapil meteorite, 149.
Méchain, 127.
Mee, A., 68.
Melloni, 76.
Mercury, 18, 80, 81-84, 97, 236.
Messier, C., 30.
Meteorites, 147, 148, 149, 229, 231.
'Meteoritic Hypothesis,' 231, 232.
Meteors, 138-149.
Meudon Observatory, 59.
Milan Observatory, 82, 202, 224.
Milky Way. See Galaxy.
Miller, W. A., 50, 172.
Mira Ceti, 11, 182, 186, 187.
Mitchel, O. M., 31.
Mizar (ζ Ursæ Majoris), 204.
Möller, A., 129.
Moon, the, 10, 24, 65-79, 90, 95, 148, 228.
Moscow Observatory, 132.
Mouchez, A., 161.
Müller, G., 175, 181.
Munich Observatory, 44, 224.

Napoleon, 67, 127.
Nasmyth, J., 73, 103.
Nebulæ, 30, 31, 207-213, 228.
Nebular Hypothesis, 33, 195, 227, 228, 229, 230, 233.
Neison (Nevill), E., 73.
Neisten, 86, 105.
Neptune, 120, 121, 135, 229, 230.
Newall, H. F., 205.
Newcomb, S., 27, 64, 78, 89, 94, 162, 168, 220, 222, 223, 224, 232.
Newton, H. A., 140, 141.
Newton, Sir I., 2, 17, 29, 77.
Nichol, J. P., 31, 207.
Nordvig, L., 192.

Olbers, H. W. M., 19, 20, 69, 98, 99, 123, 124, 125, 126, 127, 129, 130, 139, 148, 152, 153.
Olbers' comet, 125.
Olmsted, D., 138, 207.
Ophiuchi (α), 183.
Orion, 221.
Orion nebula, 10, 33, 207, 208, 209, 213.
Orion stars, 174, 193, 209, 232.
Orionis (κ), 209.
Orionis (η), 209.
Orionis (θ), 209.
Orionis (U), 181, 182, 186, 187.

Palisa, J., 100.
Pallas, 19, 99, 101.
Parallax, solar, 61, 62, 63, 101.
Parallax, stellar, 150-158, 190.
Paris Congresses, 161.
Paris Observatory, 78, 118, 171.
Perrine, C. D., 81, 108, 194.
Perrine's comet, 136.
Perrotin, H., 86, 91, 100, 114.
Peck, W., 162.
Persei (Nova), 192, 193, 194, 195.
Perseid meteors, 122, 141.
Perseus, 192, 221.
Peters, C. H. F., 100.
Peters, C. A. F., 142, 153, 155, 202.
Photography, astronomical, 54, 56, 57, 59, 75, 81, 94, 108, 113,

136, 158, 160, 161, 172, 175, 192, 193, 194, 203, 208, 209, 210, 211, 212.
Photometry, 176, 177.
Piazzi, G., 19, 20, 98, 150.
Pickering, E. C., 174, 175, 176, 177, 181, 182, 183, 185, 193, 194, 203, 204, 220, 221.
Pickering, W. H., 75, 76, 81, 91, 92, 93, 107, 113, 209.
Plana, G., 78, 79.
Pleiades, 124, 210, 217.
Pogson, N. R., 142, 180.
Pole Star, 205.
Pollux, 165, 170.
Pons, J. L., 127.
Pontécoulant, 79.
Potsdam Observatory, 46, 173, 176.
Pritchard, C., 158, 177.
Proctor, R. A., 4, 20, 38, 41, 90, 91, 104, 148, 163, 164, 218, 219, 220, 231.
Procyon (α Canis Minoris), 151, 203.
Prominences, solar, 52, 53, 55, 64.
Puiseux, P., 75.
Pulkowa Observatory, 200.

Quetelet, A., 139.

Radiant points, meteoric, 139, 144, 145, 146.
Ranyard, A. C., 106, 146.
Red spot on Jupiter, 105, 106.
Regulus (α Leonis), 164, 165.
Relative parallax, 157.
Réseau, Photospherique, 59.
Resisting medium, 128.
Respighi, L., 55.
Reversing layer, 56, 57.
Ricco, A., 87, 105.
Rigel (β Orionis), 165, 209.
Ritchey, G., 194.
Roberts, A. W., 181.
Roberts, I., 209, 210.
Roche, E., 109.
Roman College Observatory, 85.
Rosse, third Earl of, 141, 156, 207, 208, 218.
Rosse, fourth Earl of, 77.
Rotation of the Sun, 58, 59; of the planets, 82, 83, 84, 85, 86, 87, 104, 111, 112.
Rowland, H. A., 52.
Rutherfurd, L. M., 75, 169.

Sabine, Sir E., 44.
Safford, T. H., 202.
Santini, G., 159.
Savary, F., 30, 199.
Satellites, 96, 107, 108, 112, 113, 115, 120, 121, 236.
Saturn, 20, 21, 22, 97, 103, 108-113, 121, 135.
Schaeberle, J. M., 93, 107, 191, 203.
Scheiner, C., 44.
Scheiner, J., 166, 174, 176.
Schiaparelli, G. V., 82, 83, 84, 85, 86, 87, 91, 92, 114, 141, 143, 149, 201, 220, 224, 231, 235.
Schjellerup, H., 180.
Schmidt, J. F. J., 69, 70, 71, 72, 73, 104, 179, 180, 189.
Schönfeld, E., 160, 179, 180, 188, 189.
Schröter, J. H., 16, 65, 66, 67, 68, 69, 70, 74, 81, 82, 84, 85, 86, 87, 97, 99, 153.
Schwabe, S. H., 18, 43, 44, 46, 55.
Schwassman, A., 100.
Secchi, A., 52, 54, 55, 60, 72, 90, 114, 141, 170, 171, 173.
Secchi's types of stellar spectra, 170, 171, 173, 174, 175, 189, 232.
See, T. J. J., 201, 202, 236.
Seeliger, H., 110, 195, 196, 202, 206, 224, 225.
Serviss, G. P., 158.
Sirius (α Canis Majoris), 151, 170, 173, 188, 202, 225.
Slipher, V. M., 106, 114, 204.
Sime, J., 27.

Sola, J. C., 112.
Solar cluster, 221, 222.
Solar system, motion of, 26, 27, 167, 168.
South, Sir J., 198.
Spectroscopic binaries, 203, 204, 205.
Spencer, H., 218.
Spica (α Virginis), 204.
Spörer, F. W. G., 45, 46, 54, 59.
Star-catalogues, 159, 160, 161, 162.
Star-clusters, 30, 31, 32, 206, 210.
Star-drift, 164.
Star-gauging, 36, 40, 41, 224.
Stars, distance of, 150-158.
Stars, distribution of, 35, 39, 40, 198-214.
Stars, double, 28, 29, 30, 197-206.
Stars, gaseous, 171, 174.
Stars, proper motion of, 162, 163, 164, 165.
Stars, radial motion of, 165, 166.
Stars, temporary, 156, 182, 188-196.
Stars, triple and multiple, 206.
Stars, variable, 177-188.
Stellar spectra, 169-176, 187, 189, 190, 191, 193, 194.
Stellar universe, 35-42, 214, 215-226.
Stereo-comparator, 100, 101.
Stokes, Sir G., 50.
Stone, E. J., 157, 160.
Stroobant, P., 88.
Struve, F. G. W., 3, 37, 38, 40, 42, 128, 151, 153, 200, 214, 215, 216, 218.
Struve, H., 201.
Struve, L., 27, 163, 167.
Struve, O. W., 27, 110, 115, 120, 153, 156, 163, 200, 201.
Stumpe, O., 167.
Sun, 15, 16, 17, 40, 43-64, 65, 80, 81, 105, 125, 128, 170, 222, 228, 229, 230, 237.
Swift, L., 81.
Swift's comet, 136.
Tacchini, P., 55, 86, 87.
Taurus, 217, 221.
Tempel, E., 210.
Tennyson, 96.
Tidal friction, 79, 87, 233, 234, 235, 236.
Tisserand, F. F., 146.
Todd, D. P., 122.
Trans-Neptunian planet, 121, 122.
Trouvelot, E., 86, 87.
Tschermak, 148.
Tulse Hill Observatory, 171.
Turner, H. H., 194, 224.
Twining, A. C., 139.

Upsala Observatory, 59.
Uranometria Argentina, 160.
Uranus, 11, 20, 22, 23, 97, 113, 114, 115, 118, 121, 135, 141, 230.
Ursa Major, 162, 164.
Ursæ Majoris (δ), 182.
Ursæ Majoris (ξ), 199.

Venus, 18, 84-88, 97, 235, 236.
Venus, transits of, 61, 62, 87.
Vega (α Lyræ), 151, 165, 170, 172, 173.
Very, F. W., 77.
Vesta, 19, 99, 101, 102.
Vogel, H. C., 84, 88, 95, 102, 106, 114, 131, 148, 166, 173, 174, 175, 183, 184, 185, 190, 191, 193, 195, 204, 209, 232, 233, 237.
Vulcan, 81.

Washington Observatory, 96, 223.
Watson, J. C., 81, 100.
Webb, T. W., 72, 73, 104.
Weinek, L., 75.
Weiss, E., 142.
Well's comet, 134.
Whewell, W., 318.
Williams, A. S., 110, 193.
Wilson, A., 16.
Winlock, J., 177.
Winnecke, F. A. T., 131.
Witt, K. G., 101.

Wolf, Max, 100, 181, 191, 194, 211.
Wolf, R., 44, 45, 188.
Wolf and Rayet, 171.
Wolf-Rayet stars, 171, 174.
Wollaston, W. H., 48.
Wright, T., 34, 110.

Yale Observatory, 157.
Yerkes Observatory, 55, 111, 202.
Young, C. A., 54, 56, 57, 58, 60, 87, 114, 190.

Zach, F. X., 97, 98, 152.
Zantedeschi, 77.
Zenger, 85, 88.
Zöllner, J. C. F., 54, 58, 60, 84, 103, 132, 232.

CORRIGENDA.

P. 30, l. 5, *for* "objects" *read* "orbits."
P. 36, l. 13, *for* "unable" *read* "able."
P. 61, l. 17, *for* "8″.371" *read* "8″.571."
P. 63, l. 21, *for* "bases" *read* "gases."
P. 100, l. 16, *for* "Schwussmann" *read* "Schwassmann."
P. 167, l. 28, *for* "Strumpe" *read* "Stumpe."
P. 184, l. 11, *for* "star-variables" *read* "variable stars."
P. 199, l. 23, *for* "2102" *read* "1202."

THE END.

PRINTED BY WILLIAM BLACKWOOD AND SONS.

University of Toronto
Library

DO NOT
REMOVE
THE
CARD
FROM
THIS
POCKET

Acme Library Card Pocket
Under Pat. "Ref. Index File"
Made by LIBRARY BUREAU

Author Macpherson, Hector
Title A Century's Progress in Ost.
86421
Ashton.